An Investigation Into the Seakeeping Performance of a Series of Appended SWATH Hulls in Irregular Seas

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AN INVESTIGATION INTO THE SEAKEEPING PERFORMANCE OF A SERIES OF APPENDED SWATH HULLS IN IRREGULAR SEAS

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ABSTRACT

An investigation was made into the heave and pitch responses of a four-ship series of Small Waterplane Area Twin Hull (SWATH) ships. Motion resulting from heave and pitch for a point on the bow at the centerline was calculated for ahead seas representing travel at Froude numbers between 0.0 and 0.5 in irregular waves with significant heights of 5 to 25 feet. The hulls were based on the DTNSRSC contoured hull SWATH 10 design and included variants with prismatic hulls and hulls of elliptical cross section.

The results show that the prismatic hulls exhibit a more seakindly motion envelope than those with a contoured profile. Elliptical cross sections amplify the difference in performance between prismatic profile ships and contoured profile ships by emphasizing the differences in the longitudinal distribution of the ships' added mass. It is shown by example that the occurance of a lower maximum value for a motion parameter does not necessarily imply a more seakindly ship.

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I am indebted to my wife for her patience, encouragement, and support in the execution of this work. Her love provided the necessary framework within which I was able to apply the discipline of research that I learned from my advisor, Professor D.V. Burke.

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I INTRODUCTION

PURPOSE

The purpose of this research was to investigate the operating envelope aspects of the seakeeping responses of a series of Small Waterplane Area Twin Hull (SWATH) ships. The SWATH design has been suggested as providing a more stable alternative to the monohull for both civilian and military purposes. The small waterplane area of the struts, as opposed to the large wedge/rectangular waterplane of the monohull, leads to less direct coupling between exciting wave forces and ship motions. This work seeks to explore two of the more recent modifications to the circular cylinder hulls that were the basic building blocks of the first modern SWATH designs.

The DTNSRDC SWATH 10 design, of 11,271 tons and 469 feet LOA, is the baseline ship for these studies. See Appendix A for particulars. It was initially designed with an eye to providing acceptable powering performance rather than optimizing its seakeeping performance. Drawing board SWATH designs are generally acknowledged to be inferior to equivalent monohulls of the same displacement with respect to powering requirements when used in calm water, and the

general thrust of the inovative work done in designing SWATH hulls has reflected this concern, allowing the inherent seakeeping characteristics of the design to prove the craft's operational value.

This study has investigated two modifications to the SWATH 10 hullform: (a) a regression to a prismatic version to determine the effects of contouring the hull, and (b), replacing the parallel middlebody with an elliptical cylinder. These two modifications were also combined to form a simple elliptical prismatic hull.

HULL DESCRIPTION

The baseline ship, known here as ship B0, is the SWATH 10. The hull nose is a prolated spheroid which reduces to a forward cylinder and then transitions to a large cylindrical parallel middlebody and then terminates in a parabolic tail. The strut is composed of a parabolic nose and tail joined by a section of uniform thickness. The strut and its longitudinal center of flotation (LCF) were kept constant for all four hull designs. Likewise, the hull length of the ship, the longitudinal points of transition from one hull section to another, and the longitudinal center of buoyancy (LCB) were fixed with respect to the forward perpendicular.

Displacement was constant. The fin dimensions were kept constant. The stabilizing fins were placed such that the moment arm of each fin with respect to the LCB was kept constant throughout the tests.

Ship B1 is the prismatic profile version of B0. The parallel middlebody, the forward parallel section, and the transition sections were re-defined as having equal diameters, that value being determined in a manner to ensure that displacement and LCB were constant. The diameter of the hulls is 20.56 feet.

Ship E0 is a contoured design using forward and aft sections modelled after B0. The parallel middlebody was changed to be a horizontally disposed ellipse of proportions 1.2 to 1. The other sections remained circular and their diameters were reduced so as to maintain the same proportion to the vertical dimension of the parallel middlebody that the original diameters had with respect to the middlebody diameter of the baseline ship. The transition sections immediately forward and aft of the elliptical cylinder change linearly from ellipses to circles to match the sections at either end of the elliptical section.

The hull of ship E1 is an elliptical cylinder, having cross-sections of the same form as the middlebody of E0.

The axes of the ellipse were reduced proportionally to maintain a constant displacement, since the parallel section of E1 is much longer than that of E0.

In all cases, the setback of the strut, in reference to the nose of the hull, was adjusted such that the relationship between LCB and LCF was kept constant. The LCB remained 12.245 feet (2.878% of LBP) forward of the LCF.

SCOPE

The objective of the study was to compare the effects of differing hull geometry on the ultimate motions of a particular point on the ship. It was decided to concentrate on the point which is centerline on the bow of the ship due to the effect of that motion on potential aviation operations, for which SWATH ships are otherwise well suited due to their large free deck area and the ease with which the interior volume can be arranged.

Although the motions of other points on the ship are of interest during aviation operations, notably the stern in the presence of following seas, it was thought that observing a number of parameters at one particular point might yield the greatest degree of information. Slamming at the

stern caused by following seas is not thought to be as severe a problem as bow slamming in head seas due to the relative velocities involved. Also, in that the ship might reasonably expect to keep the wind, and therefore the seas, forward of the beam during aviation operations, this study was conducted for wave angle headings of 90 to 180 degrees. The wave angle is the relative angle between the ship's head and the direction of motion of the seas. Thus, a wave angle of 180 degrees is a head sea.

PERFORMANCE CRITERIA

Several approaches to objectively defining seakeeping criteria have been made. Perhaps the most exhaustive list of factors was assembled by Olson (1977), who evaluated the performance of a ship on the combined basis of the ship's absolute motion and the effect of that motion on the performance of a ship's crew and equipment for a particular task. Some of Olson's criteria for SWATH aviation-related tasks are listed below:

Item	Long-term limit
Roll angle	9.6 degrees
Pitch angle	2.4 degrees
Flight deck vert. displ.	2.1 feet
Flight deck vert. vel.	3.5 ft/sec
Vertical acceleration	0.2g (RMS)
Slamming	1 slam / 2-5 min. (about 25/hr)

All numbers are for significant values.

Motion sickness incidence is another factor by which to judge the stability of an ocean platform. The Motion Sickness Index (MSI) (O'Hanlon and McCauley, 1973 and McMullen Assoc., 1976), itself a statistical determination, is the expected percentage of unacclimatized young adult males experiencing emesis within a given period of exposure. MSI charts are complicated by the dependence of tolerance on the frequency of the motion as well as the acceleration of the subject. A figure of 20% of the crew indisposed at any one time has been proposed by some ergonometricians as the appropriate design value based on historical precedence, but no Navy studies have substantiated that number to date. MSI was not used as a performance criteria in this study due to the additional difficulty involved in presenting this data.

The roll angle limitation was not explored due to the point of interest for which motions were calculated, the weak interactions between pitch and roll motions, and the

difficulty of exercising an additional numerical tool in the time available. It is obvious that roll motion affects deck operations undertaken at the extreme beams of the ship. It was initially estimated that roll motions would not, however, be significant for centerline, deck level evolutions.

Pitch limitations have been frequently cited as an operational limit on some ship subsystems and a value of 2.4 degrees RMS has been selected by several authors as significant. Due to previous works which cite pitch as being of greater importance than heave in creating vertical motion at the bow, this study absorbed vertical motion due to pitch into the total vertical displacement of the bow.

Baitis (1975) gives operational limits on the vertical displacement and velocity of a helicopter landing zone. The values of 2.1 feet and 3.5 ft/sec were specified as appropriate to helicopter operations. Baitis's value for vertical acceleration for these operations is 0.275g (RMS). Alternately, Aertssen (1972) states that a commercial ship captain will slow down or alter course if the significant vertical acceleration exceeds 0.2g (RMS). The value of 0.2g was selected as being more appropriate to naval scenarios of long duration and to offer a safety factor for the operations conducted.

Common practice among ship captains is to allow a severe slam not more frequently than 3 times in 100 cycles. Bales (1978) suggests 4 times in 100 cycles. These and Lamb's (1975) estimate for allowable 1/10th highest average relative motion between the cross structure and the waves lead to the equivalent of roughly one significant wave contact every 2-5 minutes. An intermediate value of 25 slams/hour was chosen.

LIMITATIONS OF SCOPE

1. The study was limited to ahead seas and the investigation of the indices mentioned above.

2. Confirmation of the analysis was not obtained by the use of tow tank models.

3. SWATH ships in this displacement range have not been built to date; U.S. experience thus far with SWATH ships has been limited to the SSP Kaimalino.

II MOTION EXPECTATIONS

The equations of motion for a SWATH can be divided into two separate groups: (i) the heave and pitch equations and (ii) the roll, sway, and yaw equations. In one of his works on the theoretical motions of this type of vessel, Lee (1976) derives the basic equations of motion for the SWATH hull using two-dimensional potential flow results from oscillating cylinders in deep water (Frank, 1967 and Lee, 1971). The velocity potential functions were formed by the method of source distributions. Strip theory was then introduced to give the total flow past the hull, under the assumption of small deviations of the flow from the normal, that is, the angle of incidence, α, is small.

For incompressible flows around slender bodies subject to moderate incidence angles, it can be shown (Thwaite, 1960) that the vertical force, F_v, can be expressed in the form:

$$F_v = (\rho/2)U^2 A_p \sin\alpha\,|\sin\alpha|\,(a_o|\cot\alpha| + C_D) \qquad \text{eqn (1)}$$

where: A_p = projected area of the body onto a horizontal plane

α = trim angle

a_o = viscous-lift coefficient

C_D = cross-flow drag coefficient

In experiments with airships of circular or polygonal cross sections, a_o was found to be about 0.07 and C_D to lie in the range of 0.4 to 0.7. This study used 0.07 and 0.5 respectively.

For regular harmonic oscillation in the vertical plane at constant forward speed, equation (1) becomes:

$$F_v = (\rho/2)\, A_p(U^2 a_o \alpha + C_D\, w|w|) \qquad \text{eqn (2)}$$

where: w = relative fluid velocity with respect to the body and is given by:

$$w = \partial\xi_3/\partial t - x\partial\xi_5/\partial t + y\partial\xi_4/\partial t - \partial\zeta_v/\partial t(x,+/-b(x),-d_1(x)) = U(\alpha - \dot{\xi}_5) \qquad \text{eqn (3)}$$

where:

ξ_i = displacement of the ship in the i^{th} mode from its mean position

$\partial\xi_i/\partial t$ = velocity of the ship in the i^{th} mode from its mean position

ζ_v = vertical velocity of the fluid induced by the wave

$b(x)$ = transverse distance from the x-axis to the midpoint of the beam of one hull

$d_1(x)$ = depth to the maximum-breadth point at a cross section

The angle of incidence can be expressed as:

$$\alpha = \xi_5 + (\partial\xi_3/\partial t - x\partial\xi_5/\partial t + y\partial\xi_4/\partial t$$

$$- \partial\zeta_v/\partial t(x,+/-b(x),d_1(x)))/U \qquad \text{eqn (4)}$$

Equations (1) thru (4) assume that α is small and that the diffraction of the incident wave can be neglected. As the ship exhibits port-starboard symmetry, the term $y\partial\xi_4/\partial t$ will not contribute to the vertical force. The vertical force induced on the two hulls is then:

$$F_v = (\rho/2)U^2 \int_L B_m(x)\Sigma(a_o\alpha_i(x) + C_D(\alpha_i+\xi_5)|\alpha_i-\xi_5|)dx$$

eqn (5)

where $B_m(x)$ is the maximum beam of the submerged hull and α_1 and α_2 are the angles of incidence for the port and starboard hulls. By defining:

$$\partial z_1/\partial t = \partial z_{1P}/\partial t + \partial z_{1S}/\partial t$$

$$\partial z_{1P}/\partial t = \partial\xi_3/\partial t - x\partial\xi_5/\partial t - \partial\zeta_v/\partial t(x,b(x),-d_1(x))$$

$$\partial z_{1S}/\partial t = \partial\xi_3/\partial t - x\partial\xi_5/\partial t - \partial\zeta_v/\partial t(x,-b(x),-d_1(x))$$

F_v can be written as

$$F_v = (\rho/2)\int_L B_m(x)\{2a_oU^2\partial\xi/\partial t + a_oU\partial z_1/\partial t$$

$$+ C_D((\partial z_{1P}/\partial t)|\partial z_{1P}/\partial t| + (\partial z_{1S}\partial t)|\partial z_{1S}/\partial t|)\}dx$$

eqn (6)

For the pitch moment, the equation is:

$$M_P = (-\rho/2) \int_L x B_m(x)\{2a_o U^2 \xi_5 + a_o U \partial z_1/\partial t$$

$$+ C_D((\partial z_{1S}/\partial t)|\partial z_{1S}/\partial t| + (\partial z_{1P}/\partial t)|\partial z_{1P}/\partial t|)\}dz$$

eqn (7)

In a similar manner, the horizontal force and moment may be defined. These horizontal components will not be detailed as they are not needed due to the limitations of this study.

When it oscillates in the vertical plane, the SWATH, being a semi-submersible, does not create large surface waves. This lack of a significant energy dissipation mechanism means that the wavemaking damping of SWATH ships in vertical-plane modes (i.e., heave, pitch, and surge) is relatively small compared with that of conventional ships. When the viscous effects contributing to the damping are neglected, the computed motion for frequencies in the neighborhood of resonance is similar to that of a typical underdamped linear system, i.e, a narrowly tuned, high spiked motion at the resonant frequency. Accordingly, SWATH models at speed have exhibited a resonant motion when they are subjected to continuous single-frequency harmonic wave excitations.

Distinct discontinuities in the response transfer functions become apparent at certain frequencies due to standing waves trapped between the two hulls. The sway and heave added mass coefficients (a22 and a33) obtained theoretically and experimentally for this particular case correlate fairly well; the requirement being that the motions must be of small amplitude. Oscillations taken beyond the small amplitude range do not exhibit pure resonance at critical frequencies due to viscous damping caused by the eddies surrounding the hull, especially in pitch and heave. This viscous damping eliminates the discontinuities in the transfer functions. Introducing cross-flow terms as corrections to strip theory, although not justified in a strictly theoretical sense, gives the engineer a practical solution until a more rigorous one is developed. Using this theory to calculate the motion in irregular waves simulating unidirectional head seas for a geosim of SWATH 6A with a displacement of 14,100 tons has shown very good agreement with experimental results when identical spectra are used (Lee, 1976).

Experimental results seem to indicate that the most important seakeeping characteristics for SWATH ships are pitch and heave motions in head and following seas and roll and sway motions in beam seas. The maximum bending moment

for SWATH ships, as well as conventional catamarans, for example, occurs in beam seas at zero speed.

PITCH AND HEAVE

Pitch motion accounts for the largest portion of the vertical bow or stern displacement. The largest pitch responses usually occur over a wavelength range where the maximum energy in the sea spectrum is concentrated, that is, a frequency of 0.3 to 0.5 radians per second for fully developed seas; the largest heave responses occur in a wavelength range for which the wave amplitudes are quite small, frequencies below 0.25 radians per second. For a SWATH ship, the maximum pitch occurs at a wave length which is approximately five times the ship length, while for a monohull the maximum pitch occurs at a wave length approximately equal to ship length. This means that for a 200-foot SWATH ship, one needs a swell of approximately 1000 feet in length to obtain the maximum pitch motions. Pitching motions for an unappended SWATH are quite often most severe in a following seaway and may have approximately the same order of magnitude as that of a monohull of the same length heading into the same seaway (Lee 1976). SWATHs without foils or control surfaces will exhibit motions of considerable magnitude. At zero forward speed in head seas, the vertical

motions of appended SWATH ships will be of approximately the same magnitude as those for a monohull with equivalent length. On the other hand, in quartering and following seas, a SWATH ship will pitch more than a conventional monohull with equivalent displacement if not equipped with foils or control surfaces.

ROLL

Salveson (1972) shows that in all beam sea conditions, except for extremely long waves (about five times the ship length), the roll motions of SWATH ships are much smaller than the roll motions of monohulls as well as conventional catamarans. As a result, the deck edge motions, especially acceleration, are much less than for both the monohull and the catamaran. However, at zero speed in head seas, the vertical motions of the deck edge which are caused by roll are approximately the same as those of conventional catamarans or monohulls of the same length.

FINS AND FOILS

As has been stated, the use of fins and active foils is very effective in reducing the motions of SWATH ships in

following seas. For stability, the aft fins should be larger than the forward fins to counteract the so-called Munk's moment. The angle of attack on the fins is proportional to the vertical velocity of the fins when the ship has a forward speed.

The hydrodynamic coefficients of a SWATH ship with stabilizing fins are the sum of the effects of the potential flow, viscosity, and the fins; the final expressions for the hydrodynamic coefficients to be used in the equations of motion can be obtained by summing the coefficients of the individual components under the assumption of superposition. One result of this was that the heave-heave damping coefficient, b33, roughly tripled by the use of fore and aft fins in an example given by Salveson.

SEA SPECTRA

The sea energy spectrum must be considered in conjunction with the transfer function when calculating the motion of a ship. Commonly used spectra include the Pierson-Moskowitz single parameter spectrum which is defined in terms of the peak value, a function of wind speed. The P-M spectrum describes a fully developed sea. Other spectra used in seakeeping analyses are the Bretschneider, the

JONSWAP, and the Ochi. The Bretschneider spectrum allows the sea to be viewed as developing, fully developed, or dissipating, by specifying both peak value and modal frequency. The Joint North Sea Wave Project (JONSWAP) spectrum was developed to describe conditions in the North Sea. Experimental data gathered in the Caribbean Sea indicates that the JONSWAP formulation might also be applicable there and for other smaller ocean areas. The Ochi spectrum, like the Bretschneider, is capable of describing a sea of two modal frequencies. In addition, the sharpness of the peaks may be specified. The Ochi was created for the analysis of Northern Pacific structures and ships.

The P-M spectrum was selected for this study so that the number of variables under consideration might be minimized. The P-M is also closer to having a Rayleigh distribution than are the other spectra, which makes it more useful for the study of stochastic processes, like responses to irregular seas.

The major underlying assumptions for the concept of superposition are that the relationship between the wave excitation and ship response is linear, that wave and ship motion are stationary, normal random processes with zero mean, and that the spectral density functions of the waves and the ship's motion are narrow banded. Since the response

predictions are made under the assumption of linearity and the Rayleigh probability distribution function, it is tacitly assumed that distribution of the motion amplitudes follows the Rayleigh function and this may not be quite true in some cases.

Normally, the relative motion prediction is less reliable than other motions because the theory does not account for the deformation of the incoming waves caused by the diffraction by the body and by the body motion. Wave deformation near the bow of a SWATH is less than one would expect for a monohull ship and offers the best opportunity for accurately modeling this effect. For example, SWATH 6A calculations agree well with experimental results in the case of bow-quartering waves. For those cases in which the designer is confident that the degree of wave deformation will not materially affect the calculations, the probable number of slams sustained for each "n" seconds by the cross-deck bottom of a SWATH ship is given below:

$$N_s = (n/2\Pi)(E_v^{(R)}/E^{(R)})^{1/2}\exp(-C_o^2/2E^{(R)}) \qquad \text{eqn (8)}$$

The superscript (R) denotes the relative motion of the point of interest.

E = variance of the motion amplitude

E_v = variance of the velocity

C_o = vertical distance from the calm waterline to the cross structure bottom

If C_o is taken to be the deck height, equation (8) gives the number of deck wettings per "n" seconds.

EXPERIMENTAL RESULTS

In experiments reported by Kallio (1976), he shows that the existence of a bow fin is responsible for quite a reduction in motions and accelerations. Motion pictures of calm water experiments indicate this may be due to the fact that the bow fin was located near the longitudinal position on the strut where the flow velocity of the wave coming from the strut leading edge was downward. (See Figure 1.)

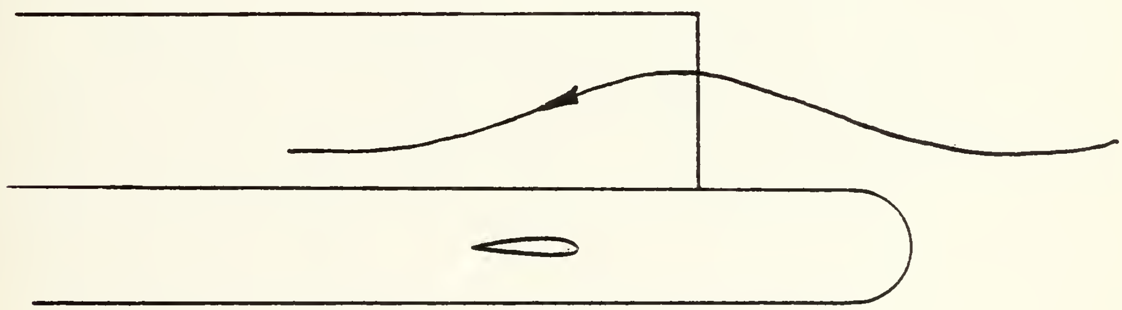


Figure 1

Experiments conducted in head seas showed that relative bow motion and pitch decreased significantly as the model's

speed was increased from zero to a scale speed of twenty-eight knots. In addition, for beam sea experiments, roll and roll acceleration decreased as speed increased in this speed range for those models.

In following seas experiments, it has been observed that surge, especially for smaller hulls, can be an important source of a de-stabilizing pitch moment. The experimenters attempted to manually control the surge by modulating the power applied to the propellers, but this proved quite unrealistic. Sudden increases in motor power to keep the craft from surging aftward would make the bow rise sharply, thus invalidating the pitch, relative bow motion, and bow acceleration data.

At near zero encounter frequencies, the model was very responsive to fin control. Active control of the fins at other encounter frequencies produced about a 40% reduction in peak to peak pitch motion. However, it was difficult to manually control the craft for more than eight or nine wave encounters at a time.

RADIUS OF GYRATION

Numata (1981), using an assumption of homogeneous weight

distribution, relates that a rough estimate of the pitch radius of gyration may be made as follows:

$K(\xi_5) = 0.22L$ where L is the hull length.

Equation (9) was used for calculating the pitch radius of gyration of the ships in this study. Since the length of the hulls was constant, the radius of gyration was constant.

NUMERICAL IMPLEMENTATION

A FORTRAN computer program (McCreight and Lee, 1976) was used for all calculations of motion. The program is based on the theoretical work by Lee to which the author referred earlier. For each speed and wave angle, the added mass and damping coefficients are calculated and used to generate transfer functions for heave and pitch for the range of wave encounter frequencies desired. These transfer functions are then convoluted with a Pierson-Moskowitz spectrum, and the results given both as functions of the encounter frequency and as statistical data.

III Ship Series Responses

It was initially believed that pitch-induced vertical bow displacement would prove to be significant. The numerical studies conducted by the author indicate this is the case. A complete set of ship response plots is found in Appendix B. A discussion of the response of ship B0 is followed below by comparisons of the three other ships with respect to B0. Observe that due to the difference between the absolute coordinate system of the level water plane and the coordinate system fixed to the vessel, an increase in ship stability will lead to a corresponding increase in the slamming frequency experienced by the ship.

Ship B0

The bow motion criterion gives rise to greater operating envelope restrictions within the regime studied than do those for velocity, acceleration, or bow slamming for all sea states. The closure of the operating volume commences in the head seas/low speed regime and traverses diagonally to the beam sea/high speed region of the plot. The point of maximum disturbance begins at Fn = 0.1 and increases to Fn = 0.2. The velocity contour maximum value also begins at Fn =

0.1, but increases to a forward speed of Fn = 0.3 for a significant wave height of 25 feet. The acceleration contour tendencies follow those of velocity.

Bow slamming exhibits the same pattern as the other parameters of interest, except for the degree of closure of the operating volume. Although the absolute value of the number of slams per hour becomes quite high, operating volume closure is not as severe as is the case for displacement, velocity, or acceleration. Bow slamming is seen to be a very easy phenomenon for the ship's captain to anticipate and should create few difficulties.

Note that the forward speed associated with the maximum response, and therefore resonance, changes as a function of the significant wave height. The predominant frequencies of the Pierson-Moskowitz spectrum shift to the lower end of the band for increased significant height, corresponding to the longer wavelengths necessary to support waves of greater amplitude. The change in frequencies seen by the ship as an underdamped spring-mass-dashpot system gives rise to a shift in the frequency of maximum response, i.e., the forward speed associated with the maximum response. All of the ships had more than one critical frequency.

Ship B1

In all sea states, ship B1 exhibits better seakeeping qualities than B0. The greater dynamic stability of the vessel, on the other hand, leads to a greater frequency of cross structure slamming at higher sea states than is observed for B0.

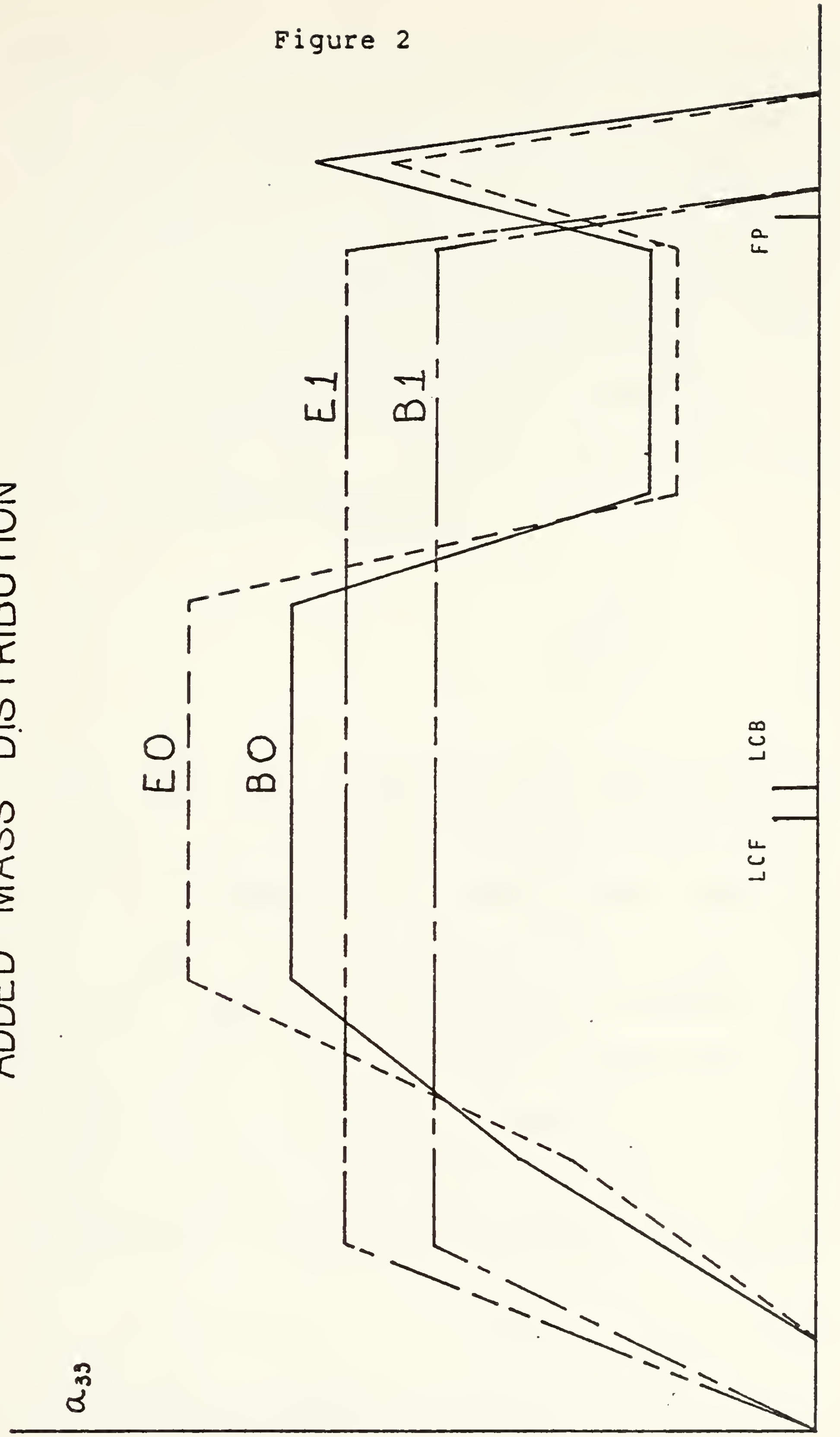
The longitudinal distribution of the heave-heave added mass coefficient is more uniform for vessel B1 since the entire hull is a full cylinder. See Figure 2.) A more uniform added mass distribution minimizes the net added mass moment taken with respect to the LCF and thus decreases the ship's bow motion. Decreases in velocity and acceleration follow from this.

Ship E0

The responses of ship E0 are only slightly different than those of B0, as might be expected since the geometry of the two ships is quite similar. B0 has a greater disparity in the distribution of the added mass than does B0. In E0, the parallel middlebody has been made elliptical and the bow and forward cylinder diameters have been reduced to maintain a constant displacement.

Figure 2

LINEARIZED GRAPH OF
ADDED MASS DISTRIBUTION



The result is a restriction of the operating envelope for all sea states. The difference first becomes apparent in the plots of bow displacement, the dominant parameter. Velocity is next affected, but the difference increases to a maximum at H = 15, and then decreases to essentially the same plot for H = 25. Acceleration and bow slamming exhibit the same trends, peaking at H = 20 with a disparity of 15% greater restriction than B0. At H = 25, the two ships have roughly the same slamming frequency.

Ship E1

E1 follows the same overall trends of B1 and is also observed to have a longer operating volume than does B0. Once again, the differences in added mass coefficient distributions cause E1 to be more seakindly than B0. This dynamic stability results in a difference in maximum slamming frequency of 37% for H = 25. The two ships have their greatest difference in slamming frequency for H = 15; E1 being 302% more likely to slam than B0. Ship E1 had the strongest dual critical frequency tendencies of the series.

E0 versus B1

A rapid comparison of these two vessels can be completed by noting their relative standings with reference to B0. Ship B1 has a larger operating envelope than E0. The difference in the distribution of a33 is more accute than when each is compared with B0. Slamming frequency tendency, as an indicator of stability in high sea states, shows E0 to be nearly twice as restrictive as B1.

E1 versus B1

Ships E1 and B1 both have nearly uniform distributions of added mass. The result is a great similarity in their respective plots. The operating envelopes of E1 do not vary greatly from those of B1, but do represent an improvement. This is consistent with their similarities is geometry.

E1 versus E0

This comparison is similar to that of B1/B0. The added mass distribution difference is more extreme for this case than for B1/B0. Consequently, the differences in the responses of the two ships can be the most extreme. The

behavior of E0 is somewhat erratic. In addition to the dual critical frequencies observed for head seas at higher Froude numbers, E0 has a third critical frequency in the vicinity of beam seas at zero speed. This caused a small error in the plotting of the velocity contours for E0, a bifurcation of the level contour, which was corrected by hand.

RESPONSE GRADIENTS

A comparison of the maximum values of a parameter for two ships, taken by itself, is insufficient for the determination of the relative sizes of their operating envelopes. The gradients of the parameter's contour must also be considered. Taking the case of ships E0 and E1 in seas of 15 feet, the bow displacement of E1 has a larger maximum value than that of E0. E1 has a greater gradient propagating from that peak value, however, and this gives E1 a larger number of speed/wave angle combinations that can be undertaken without exceeding the critical value. Most of the ship x/ship y comparisons for a given response and wave height display this effect.

IV COMBINED RESPONSE CRITERIA

In addition to observations on the behavior of individual responses, displacement, velocity, acceleration, and slamming frequency, it is useful to compare all of the responses a ship might exhibit for a given sea state to note the relative importance of those responses. Appendix C is a collection of the critical response curves for each of the ships of this series for each significant wave height that materially affects the ship's operation as an aviation platform. The critical value contours in Appendix B have been combined for each ship/sea state combination to allow comparison of the effcts of each criterion, There are no plots for a significant wave height of 5 feet as no responses were recorded above the minimum values prescribed for Appendix B.

The intent is to compare the plots and note the regions in which one response dominates the others in defining a composite operating envelope for conducting aviation operations. The first observation is that the critical, or limiting, criteria were not met simultaneously for any of the ships at any significant wave height. In all cases, the specification of a critical motion ampitude of 2.1 feet made

that response the dominant factor in defining the composite envelope. Accordingly, secondary and tertiary restrictions are noted in the following analysis of the combined criteria.

Ship B0

H = 10 feet: The displacement contour has increased such that seventy-five per cent of the possible operating environment has been denied. Velocity, as a secondary criterion, restricts the use of one-sixth the total space.

H = 15 feet: Displacement has eliminated the envelope. Velocity has restricted the use to a narrow band near beam seas at the upper end of the speed range.

H = 20 feet: Velocity continues its stricture of the envelope, under the assumption of an abandonment of displacement as a criterion. Acceleration restricts the use of half the envelope. Slamming frequency denies the operator the use of one-fourth the possible envelope. The acceleration and slamming curves overlap to prevent operation with wave angles forward of 140 degrees.

H = 25 feet: The velocity envelope tightens slightly. Acceleration restricts the use of an additional 10 degrees of wave angle. The slamming curve is now more vertical and

planar. The A/Ns cross-over point is now at a wave angle of 125 degrees.

Ship B1

H = 10 feet: Displacement has increased from less than one foot over the operating environment to the point where it quite restricts the envelope, though not as badly as for B0. Velocity has not appeared as a response of note.

H = 15 feet: Displacement nearly eliminates the envelope. Velocity as a secondary limitation, prevents the use of one-eighth the possible operating space. The slamming curve is seen for the first time.

H = 20 feet: The displacement criterion allows almost no use of the ship for aviation. Velocity restrictions double. Slamming restrictions increase moderately and the acceleration curve is initiated.

H = 25 feet: Displacement and velocity show little change. Acceleration would restrict two-thirds of the maximum envelope. Slamming has also increased.

Ship E0

H = 10 feet: Displacement causes considerable

restrictions on the ship's operation. Velocity restrictions are 50 per cent greater than for B0 at the same wave height.

H = 15 feet: Displacement has otherwise eliminated the envelope at this and all higher sea states. The velocity curve is comparable to that of B0 at a wave height of 15 feet. The acceleration curve is first seen.

H = 20 feet: Velocity is the same as for B0. Acceleration is approximately 10 per cent worse than for B0 in the same conditions. Slamming is on the order of 20 per cent worse than for B0 at this wave height.

H = 25 feet: Velocity restrictions parrot B0. Acceleration and slamming are about 10 per cent worse than for B0.

Ship E1

H = 10 feet: Displacement requirements impose far fewer restrictions on operations than for B1. Note the strong dual critical frequency characteristics of ship E1. The velocity curve is first seen.

H = 15 feet: Displacement is an extremely restrictive criteria, but less so than for the other ships of the series for this wave height. The velocity-restrictive region is split into two areas and occupies two-thirds of the potential operating envelope. The slamming curve is seen.

H = 20 feet: Displacement restrictions are on the same order as for B1 at this wave height. Velocity restrictions are slightly less than for B1. Slamming and acceleration are nominally worse than for B1.

H = 25 feet: The velocity curve is essentially the same as for a wave height of 20 feet. The acceleration curve now follows the slamming curve in the lower speed regions. Acceleration further restricts the high speed, head seas regime.

V CONCLUSIONS

1. The prismatic hulls, B1 and E1, exhibit a more seakindly motion envelope. The envelope allows for greater flexibility in operating doctrine by permitting a greater choice in speed for a given wave angle or a greater choice in heading for a given speed.

2. The added mass distribution is shown to be a major contributor to pitch, and therefore to vertical motion at the bow. The hulls with elliptical cross sections had larger values of added mass at those particular longitudinal locations than did the hulls of circular cross section. One effect of this local increase in added mass was to amplify the seakeeping charcteristics of the hull, which could result in either improvement or degradation of the ship's performance. The prismatic hull of circular cross section, B1, had better characteristics than the circular section contoured hull, B0. Changing the circular prism to an elliptical prism emphasized this; the elliptical prismatic hull, E1, had the best seakeeping characteristics of the series. Changing the parallel middlebody of B0 from a circular section to an elliptical section generated hull E0,

the worst of the series. The ship designer must be aware of this effect to avoid possible seakeeping problems.

3. It has been shown by example that the occurance of a lower maximum value for a motion parameter does not necessarily imply a more seakindly ship.

4. The vertical displacement criterion dominated the operating envelopes of all the ships for all significant wave heights. The rather restrictive value of 2.1 feet for vertical excursions was originally proposed for the bull's eye of helicopter landing zones. For similar reasons, the same value might be applied to the areas designated for V/STOL aircraft and the recovery zone for all fixed wing aircraft. The result is that the bow is seen to be an inappropriate location for these activities.

RECOMMENDATIONS

It is recommended that:

1. a new seakeeping program be written to provide a feedback loop from the irregular seas response subroutine to the ship dynamics routine to allow for the effect on the resultant ship motion of waves slamming against the underside of the cross structure.

2. more details be obtained on the flow around the fin/hull intersection. Aeronautic studies of wing tip tanks might be adapted to allow the investigation of the effects of hull diameter, D, hull dD/dx, and the presence of the strut and fin. By examining this intersection and the interaction of the anti-pitch fin trailing vortex with it, better seakeeping and design models should be possible.

3. the surge phenomenon in the presence of beam seas and for near-zero encounter frequencies be explored more fully.

4. a continuation of this study be made involving following seas.

5. geometry variations based on this series be studied more closely. The strong dual-mode envelope stricture of ship E1 is a possible problem area.

6. a continuation of this series be made by incorporating roll, yaw, and sway for the study of other points on the ship to generate a more complete set of plots for the ship designer.

7. due to the dominance of the vertical displacement of the bow, the design sequence should include this motion in determining the permissible size and location of the flight deck.

8. the lesser, included, operating envelope restrictions be taken into account in the trade-off studies of the aircraft/ship combat system. The velocity and acceleration of the deck impose additional loads on the aircraft. If the aircraft need not be strengthened to withstand these loads, they can be designed to be more efficient and effective.

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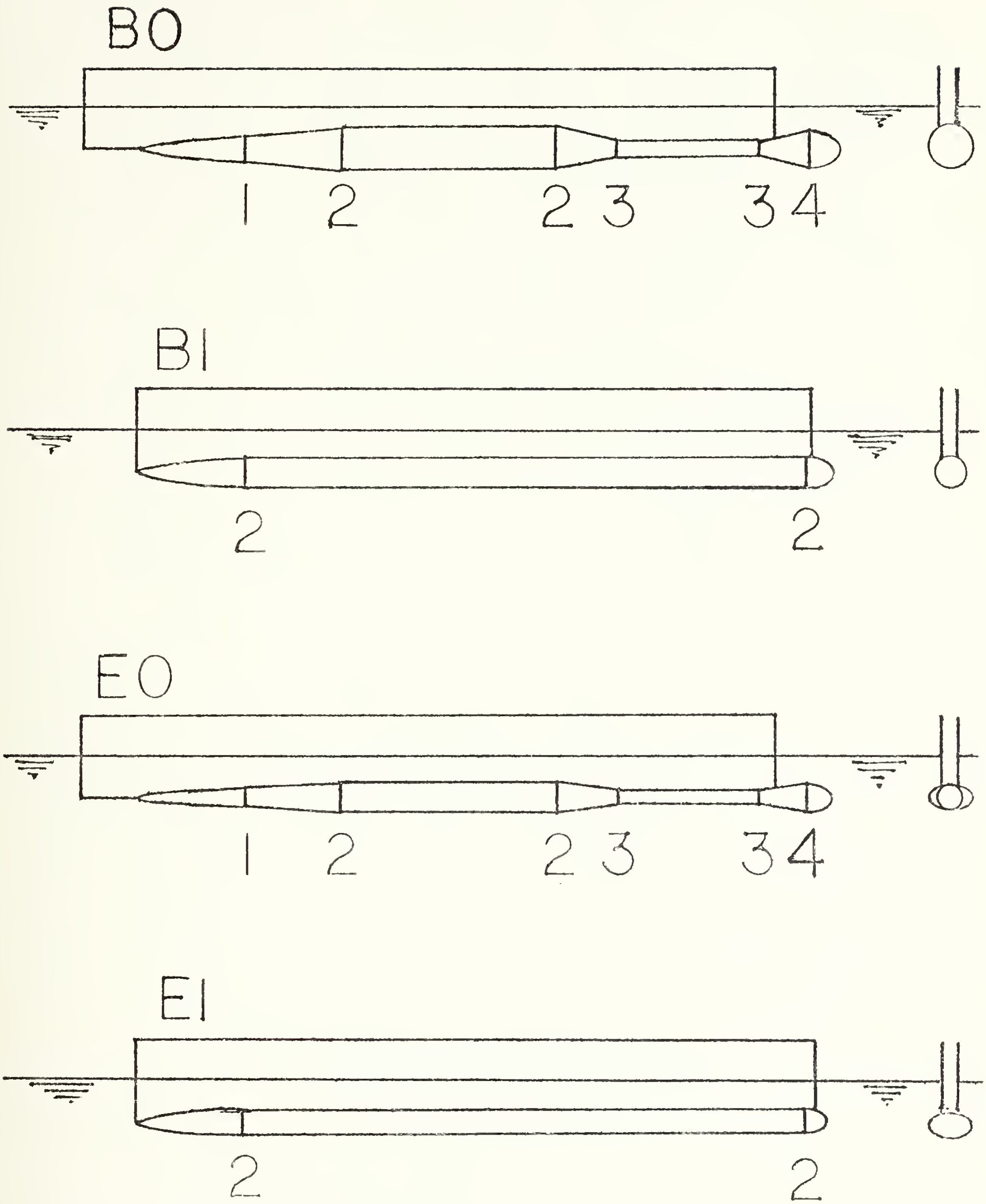
APPENDIX A

Appendix A describes the hulls used in this study. The baseline ship, B0, is the DTNSRDC SWATH 10 design, of 11,271 tons, 469 feet LOA. All dimensions are in feet.

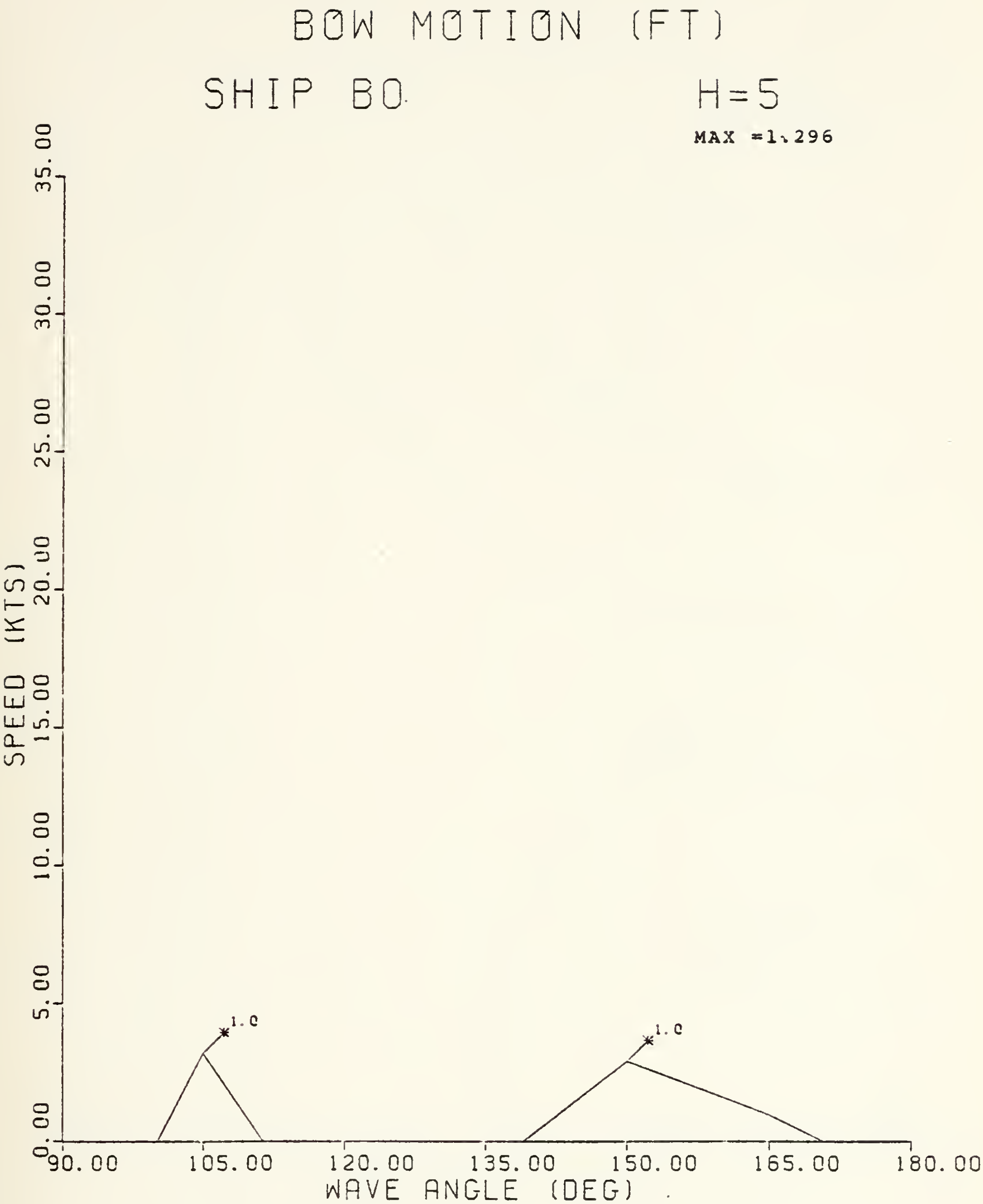

B0
1 2 2 3 3 4
B1
2 2
E0
1 2 2 3 3 4
E1
2 2

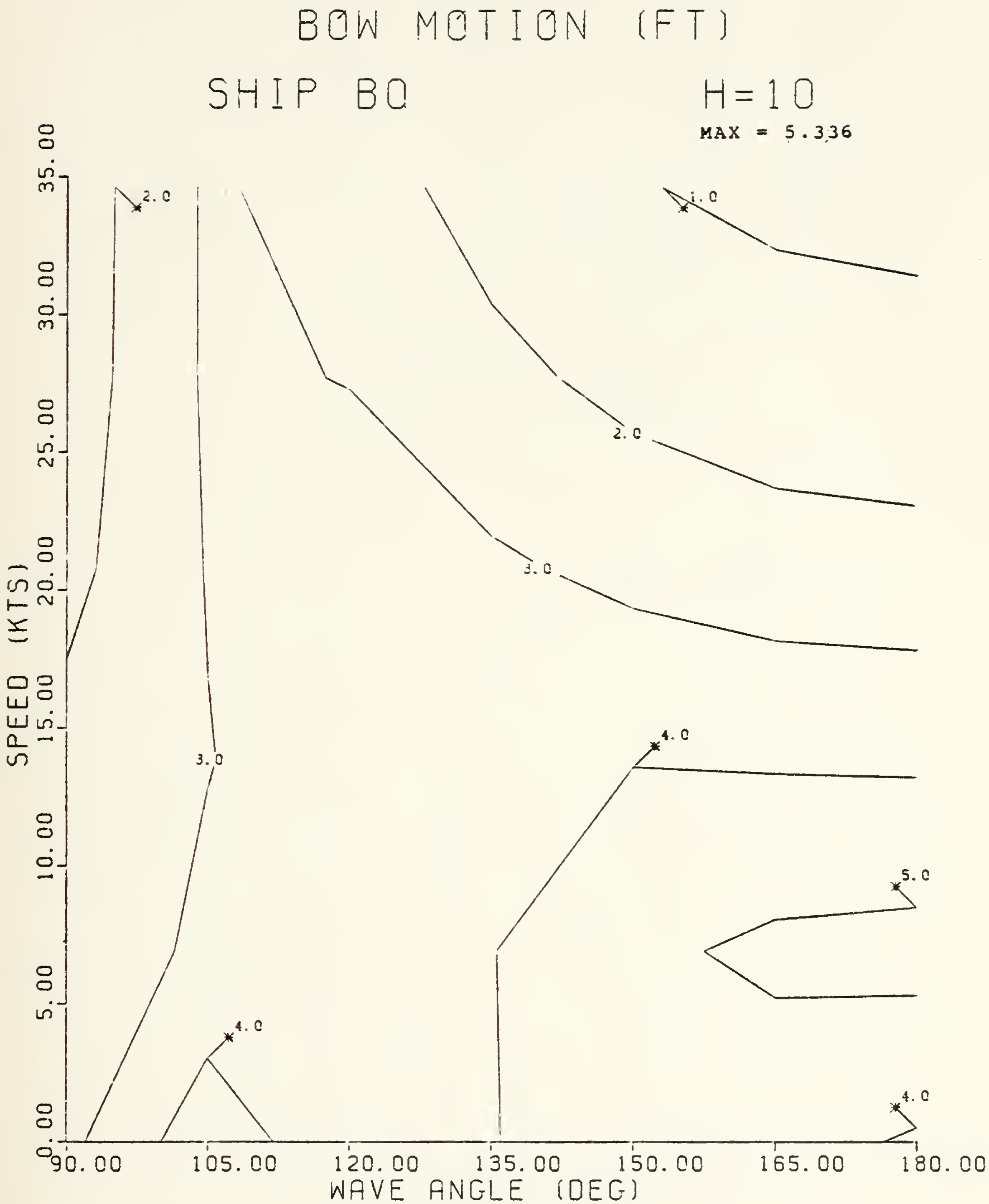
DIMENSION	SHIP B0	B1	E0	E1
L	436.4	436.4	436.4	436.4
LS	425.49	425.49	425.49	425.49
D1	18.55	---	16.93	---
D2	24.0	20.56	21.91	18.77
D3	13.64	---	12.45	---
D4	24.0	---	21.91	---
DH1	---	---	16.93	---
DH2	---	---	26.29	22.52
DH3	---	---	12.45	---
DH4	---	---	21.91	---

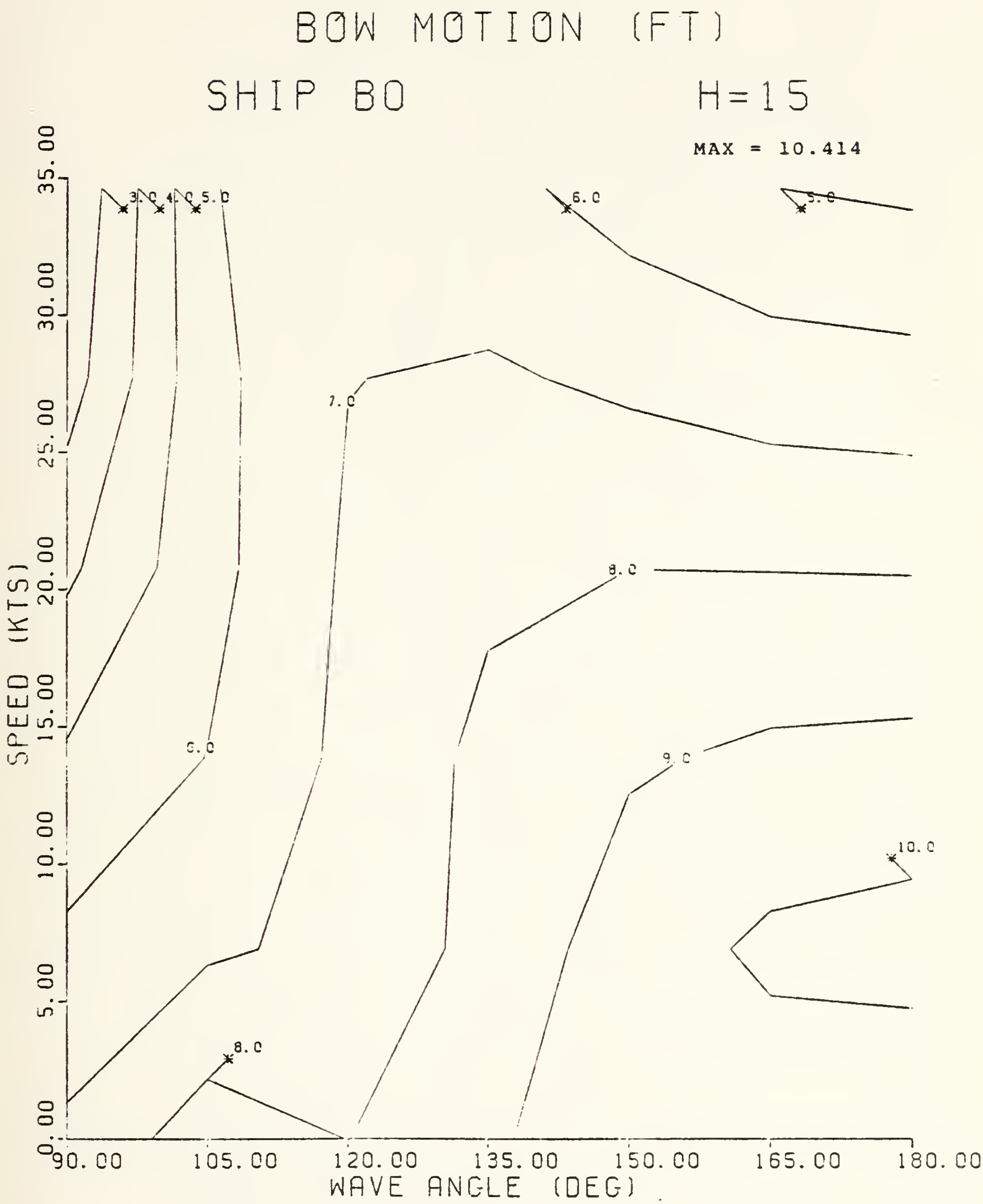
APPENDIX B

Level contours of the responses of a four-ship series of appended SWATH hulls. Plots on which no response is given and no other explanation is noted are to be taken as meaning that all values were below the minimum specified. An operating envelope is the locus of all speed/wave angle combinations which allow successful completion of a stated task. The stated task for this study is the operation of aircraft from the flight deck of a SWATH ship.

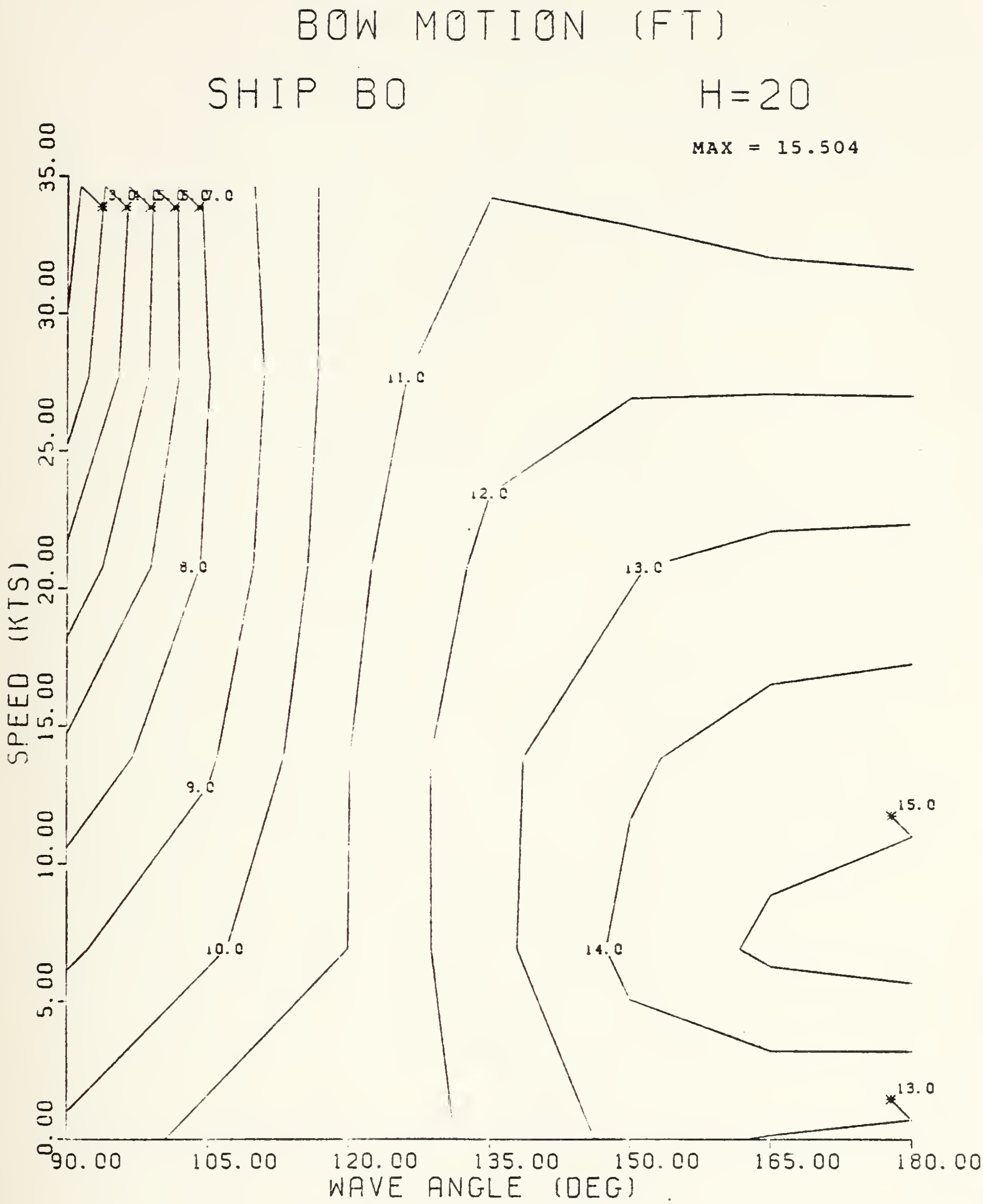
	Min. value	Max. value	Increment
Bow slams	10	100	5
Displacement	1	15	1
Velocity	1	15	1
Acceleration	3	15	1


BOW MOTION (FT)
SHIP BO
H=5
MAX =1.296
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1.0
1.0
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW MOTION (FT)
SHIP BQ
H=10
MAX = 5.336
2.0
1.0
2.0
3.0
3.0
4.0
5.0
4.0
4.0
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
SPEED (KTS)
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BOW MOTION (FT)
SHIP BO
H=15
MAX = 10.414
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0


BOW MOTION (FT)
SHIP BO
H=20
MAX = 15.504
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
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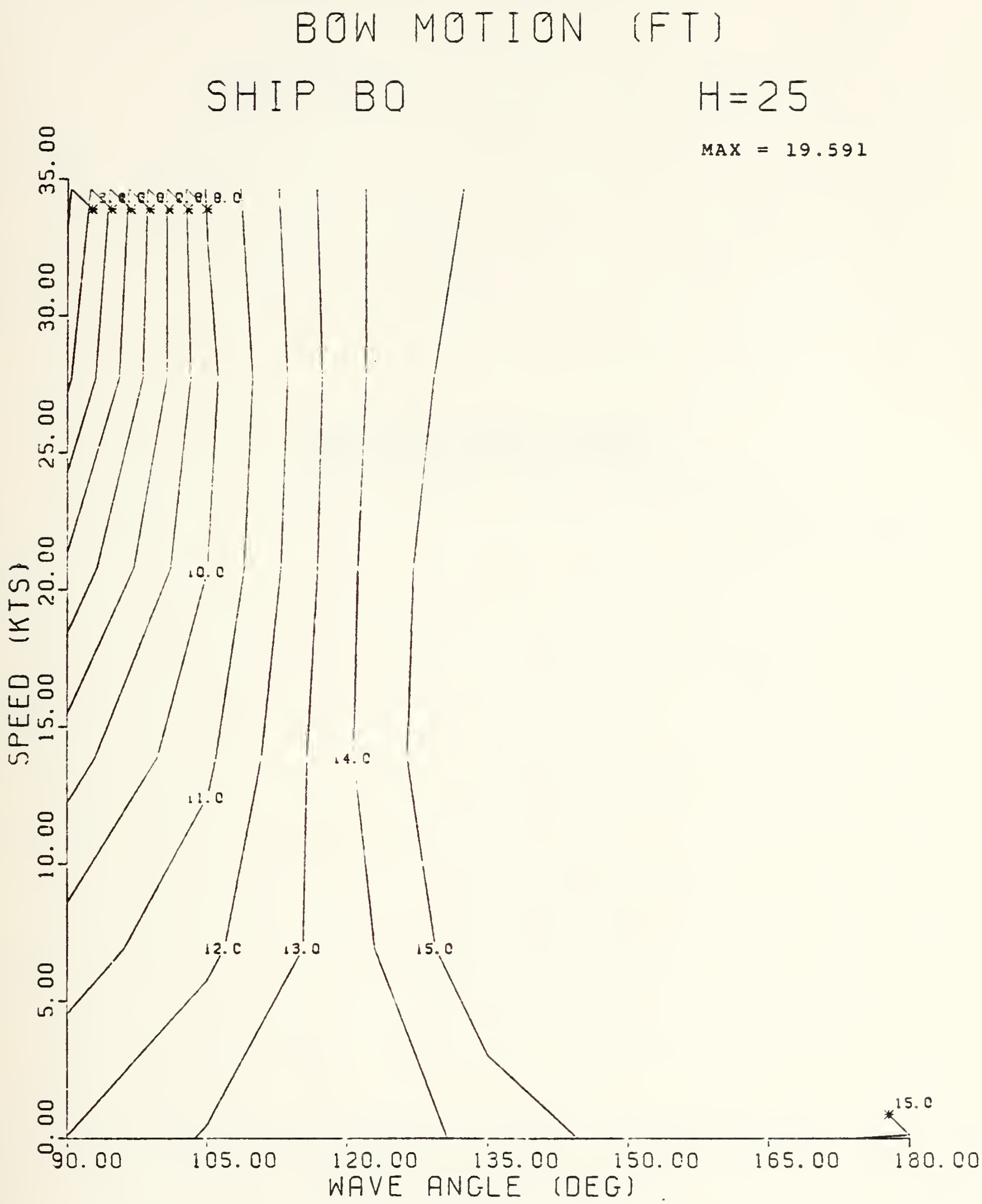
14.0
15.0
13.0


BOW MOTION (FT)
SHIP BO
H=25
MAX = 19.591
10.0
11.0
12.0
13.0
14.0
15.0
15.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

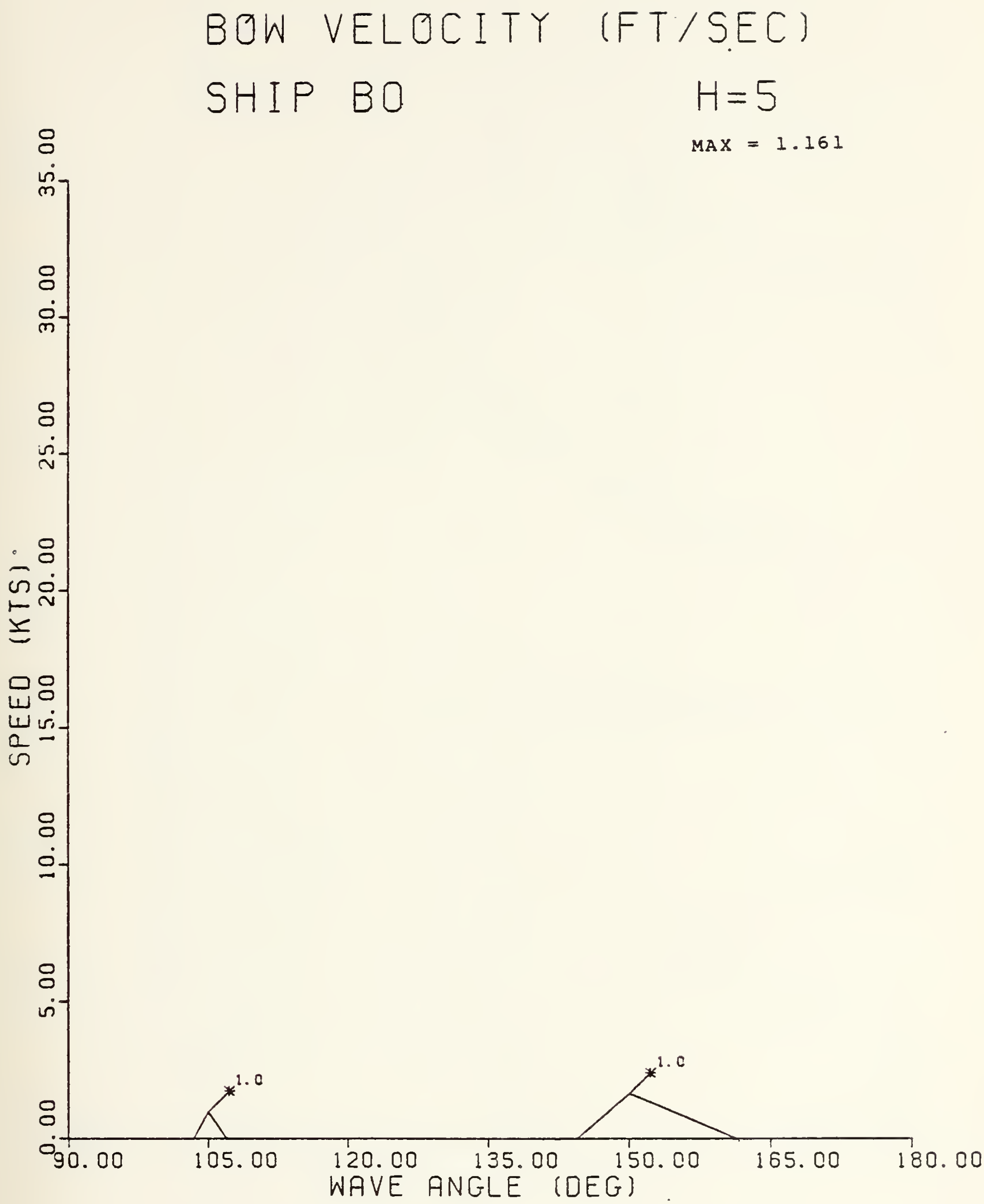
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

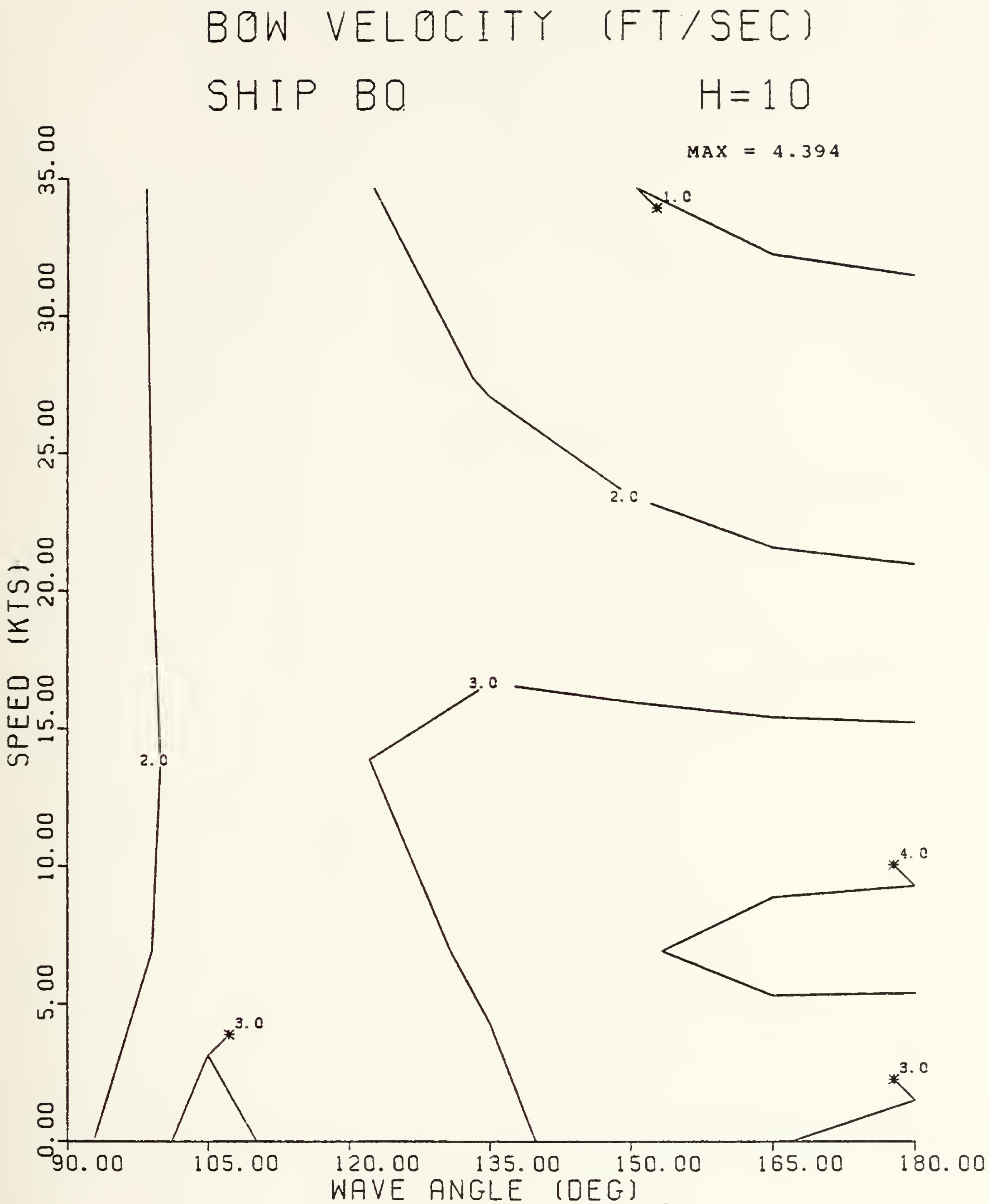
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

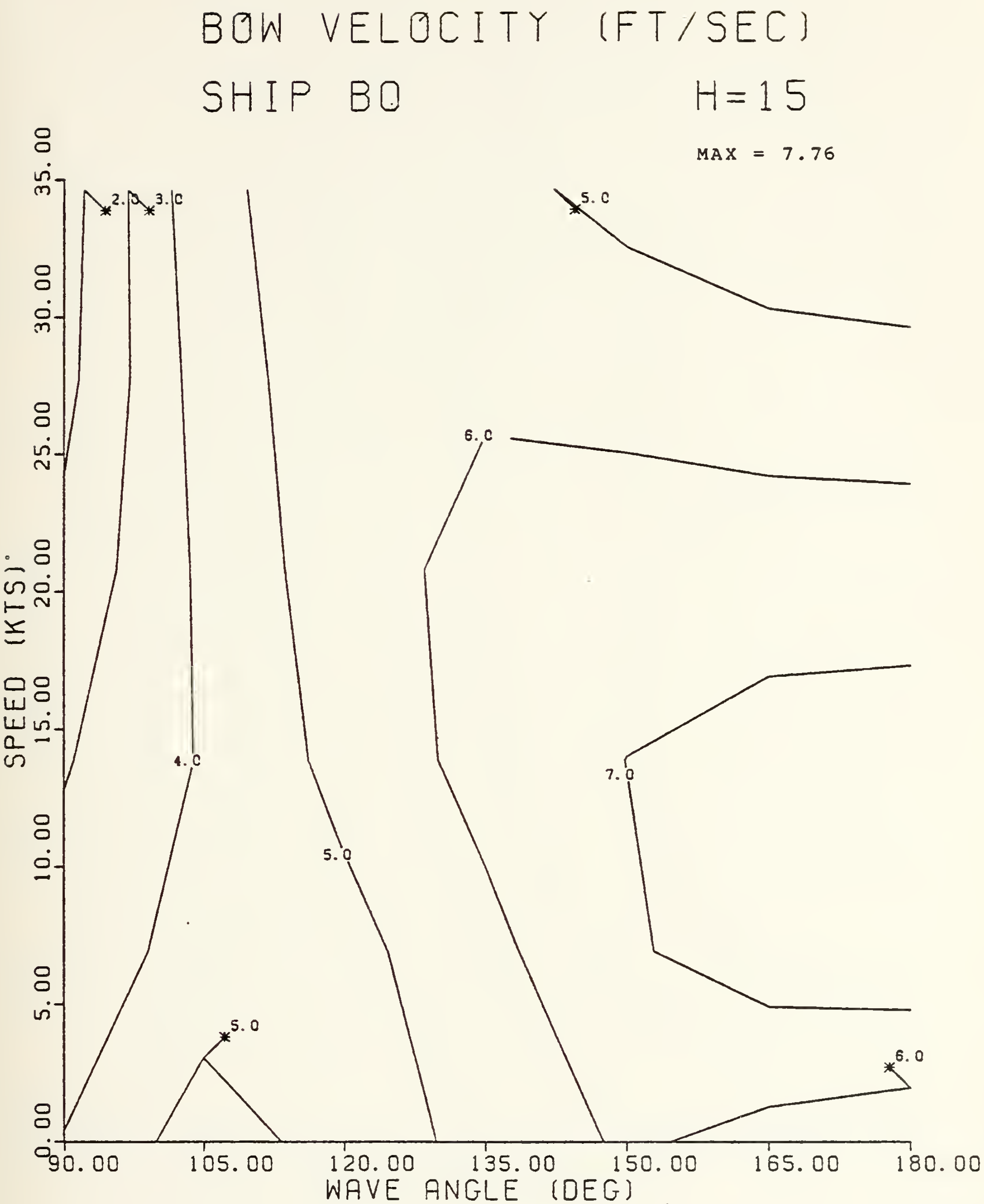
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

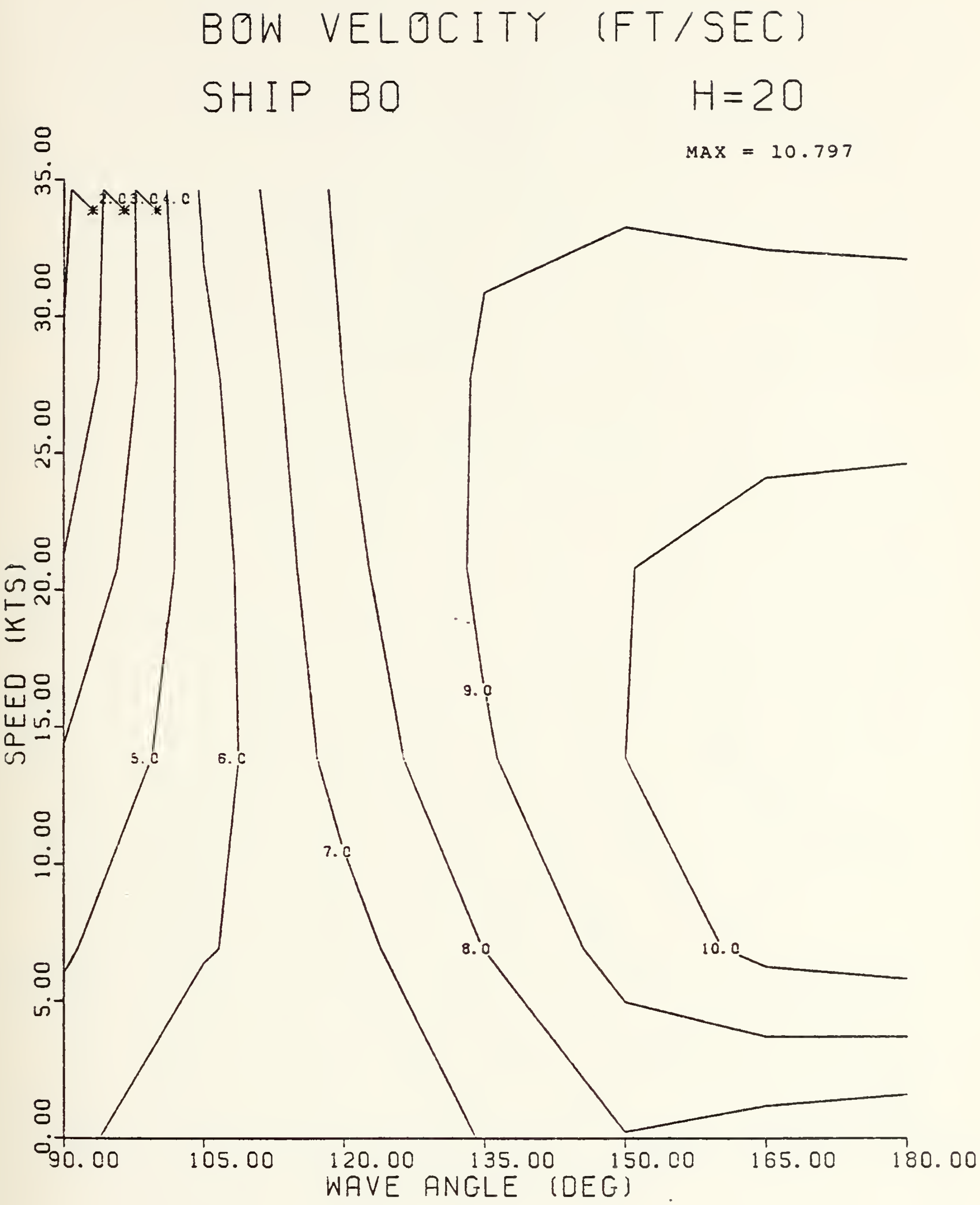
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET



BOW VELOCITY (FT/SEC)
SHIP BO
H=5
MAX = 1.161
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
1.0
1.0


BOW VELOCITY (FT/SEC)
SHIP BO H=10
MAX = 4.394
1.0
2.0
2.0
3.0
3.0
4.0
3.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BØW VELOCITY (FT/SEC)
SHIP BO
H=15
MAX = 7.76
2.0
3.0
4.0
5.0
6.0
7.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BOW VELOCITY (FT/SEC)
SHIP BO H=20
MAX = 10.797
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
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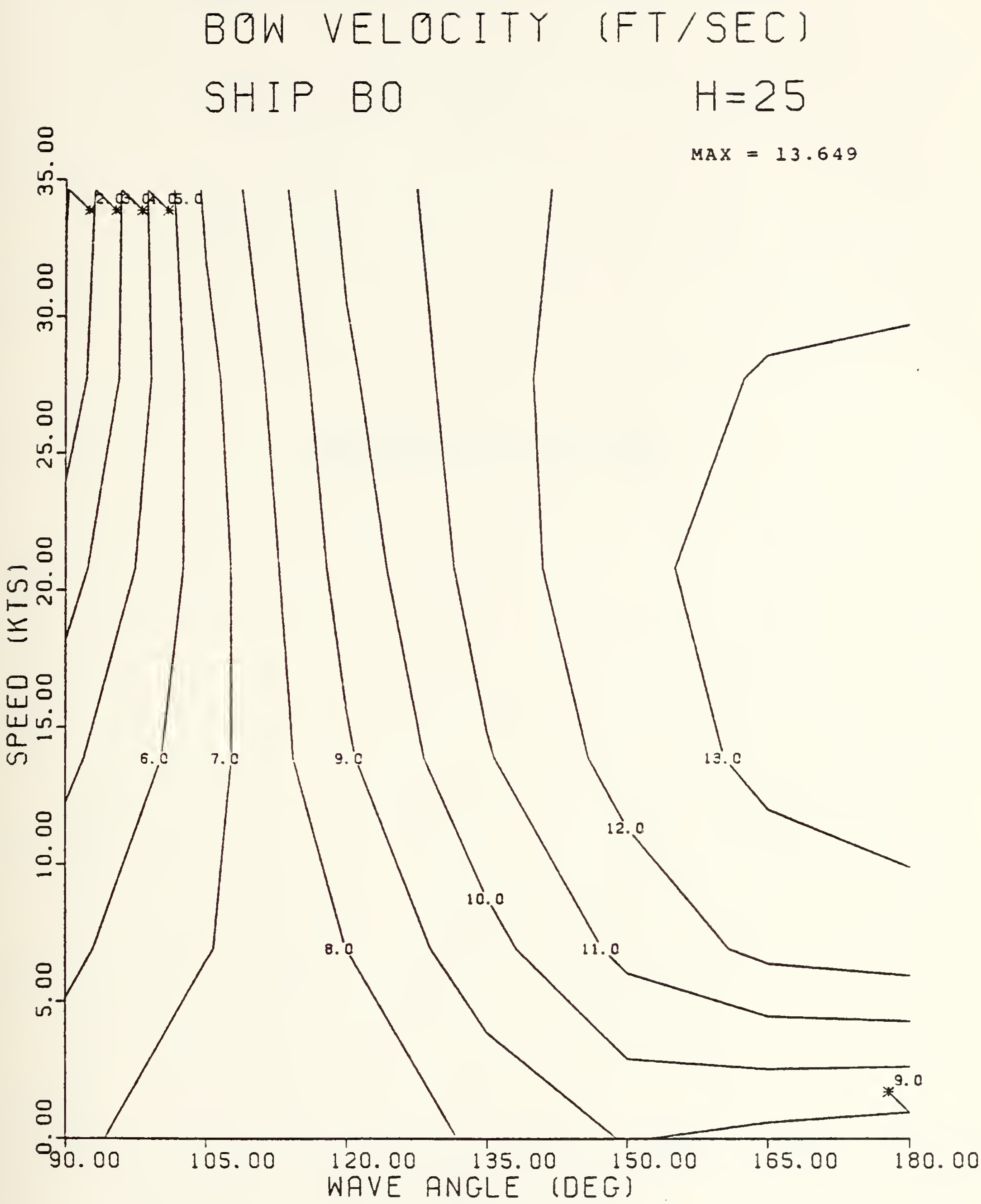
8.0
9.0
10.0


BOW VELOCITY (FT/SEC)
SHIP BO H=25
MAX = 13.649
SPEED (KTS)
WAVE ANGLE (DEG)
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5.00
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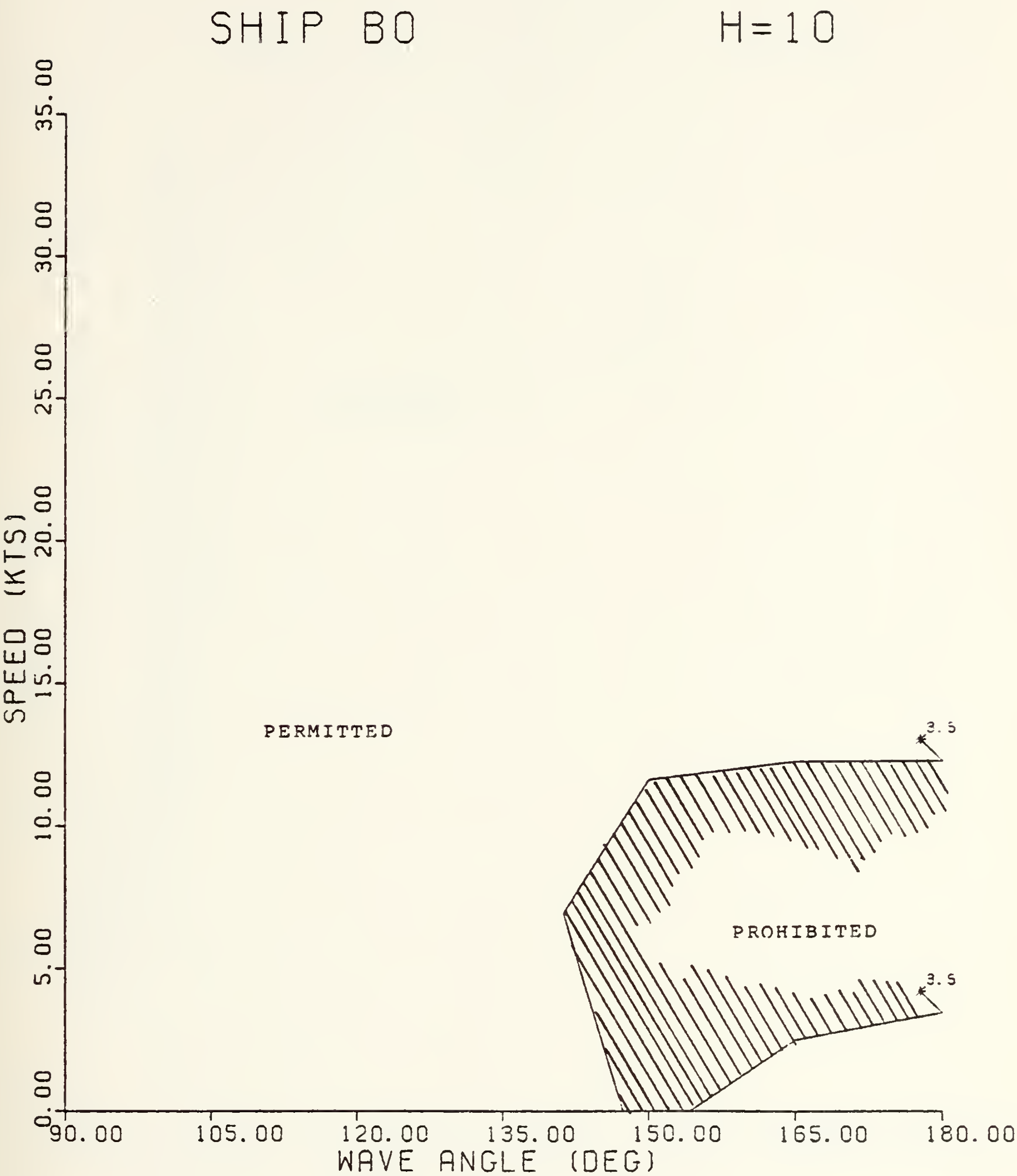
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
9.0

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC



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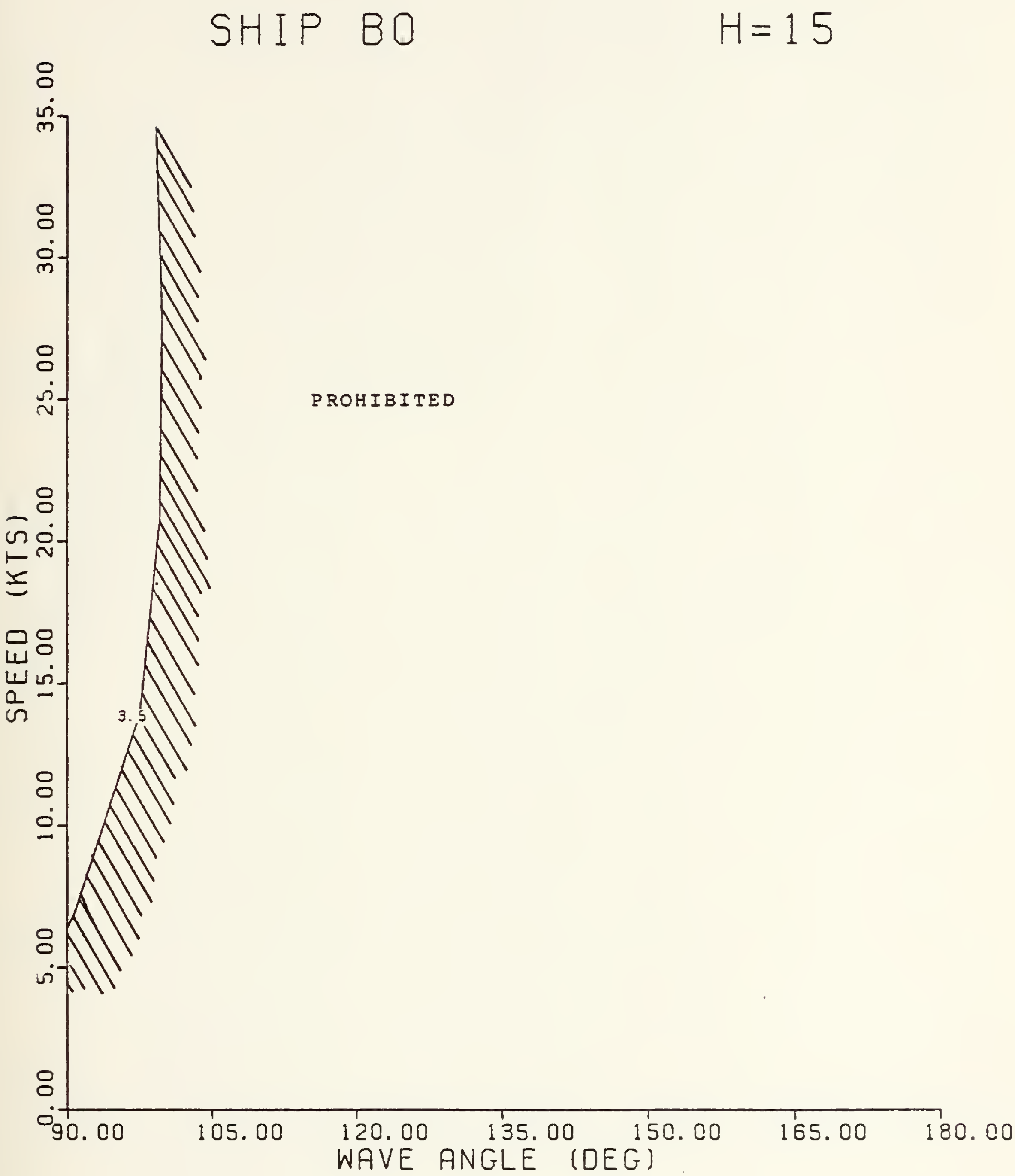

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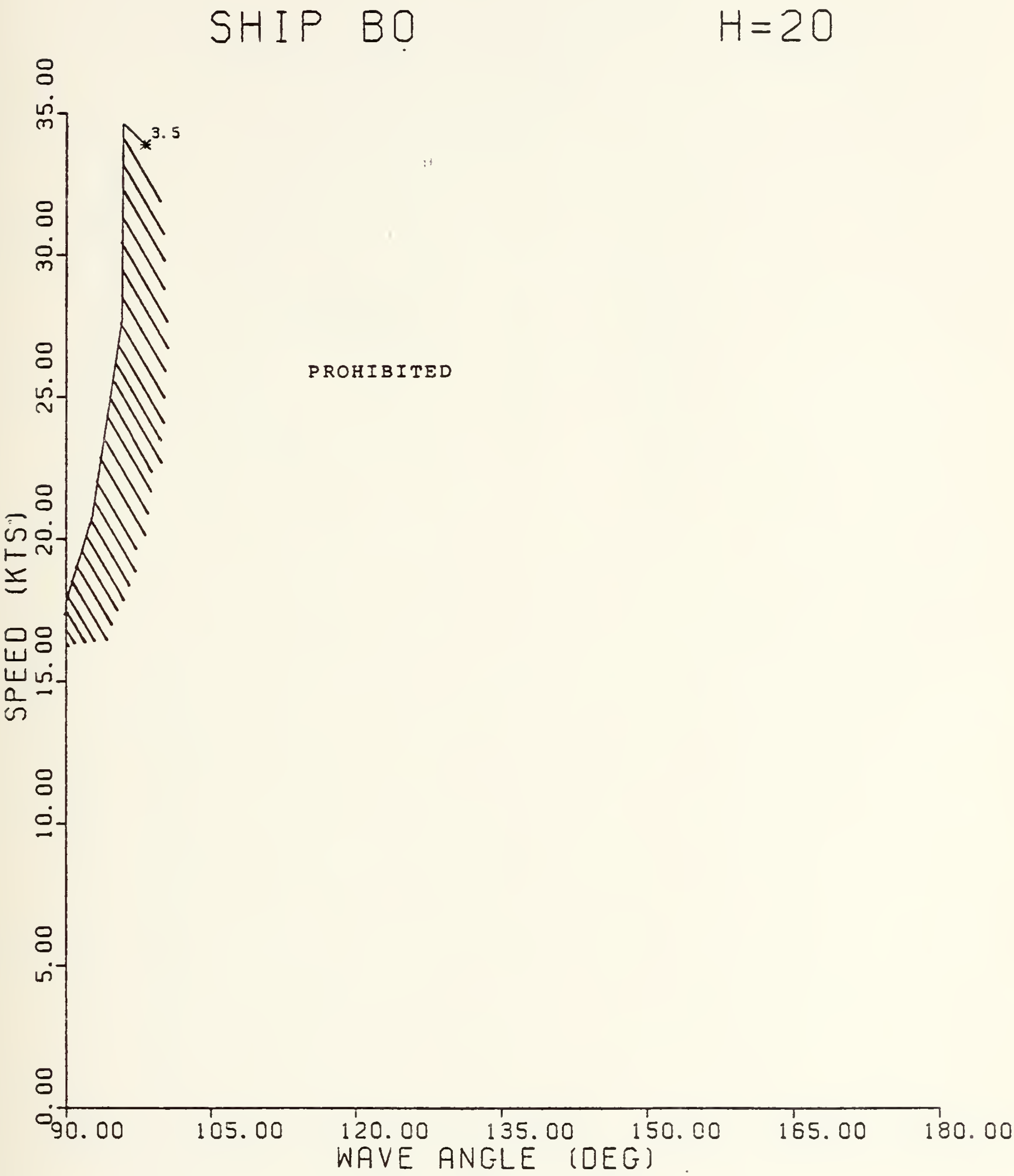
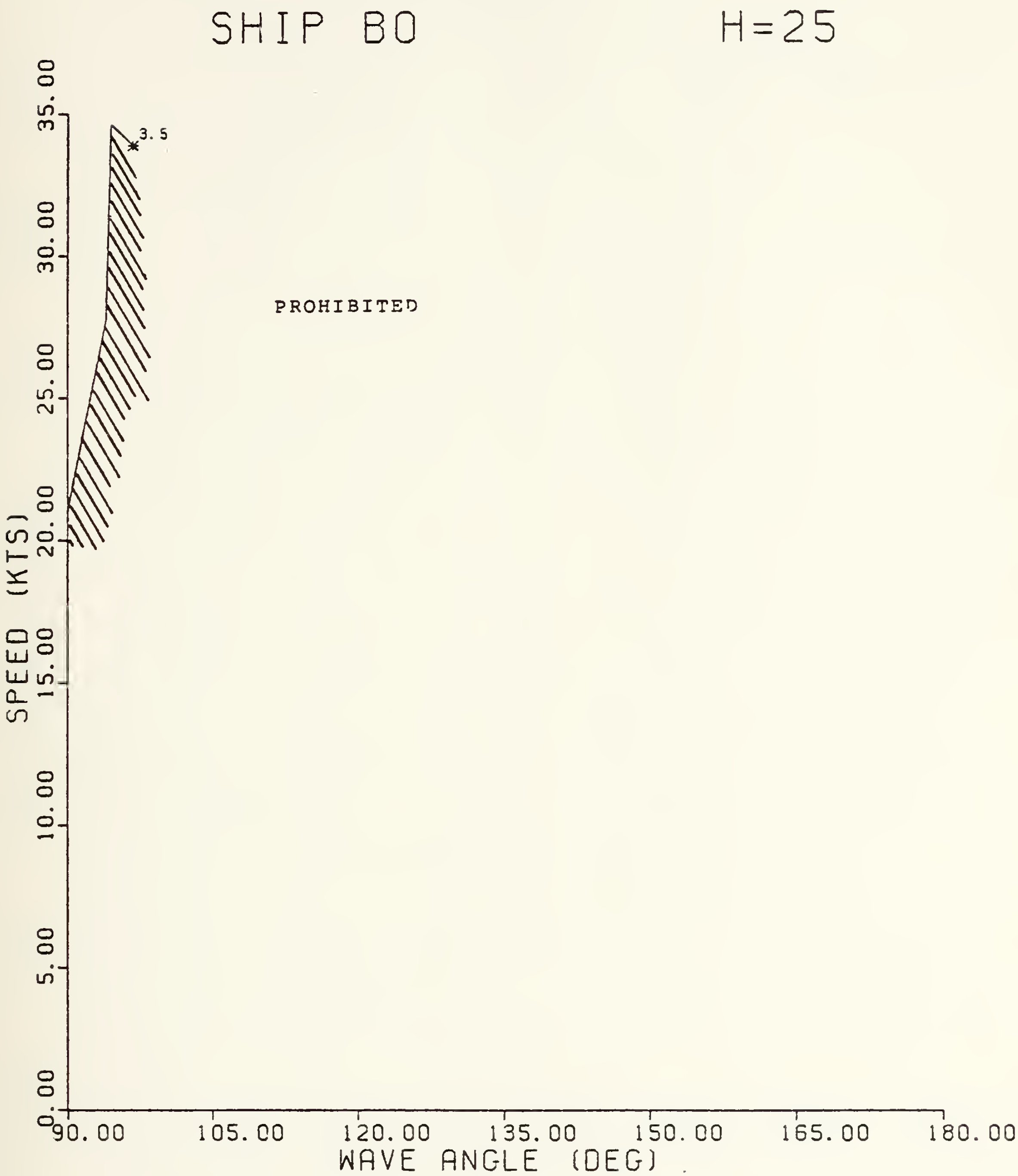
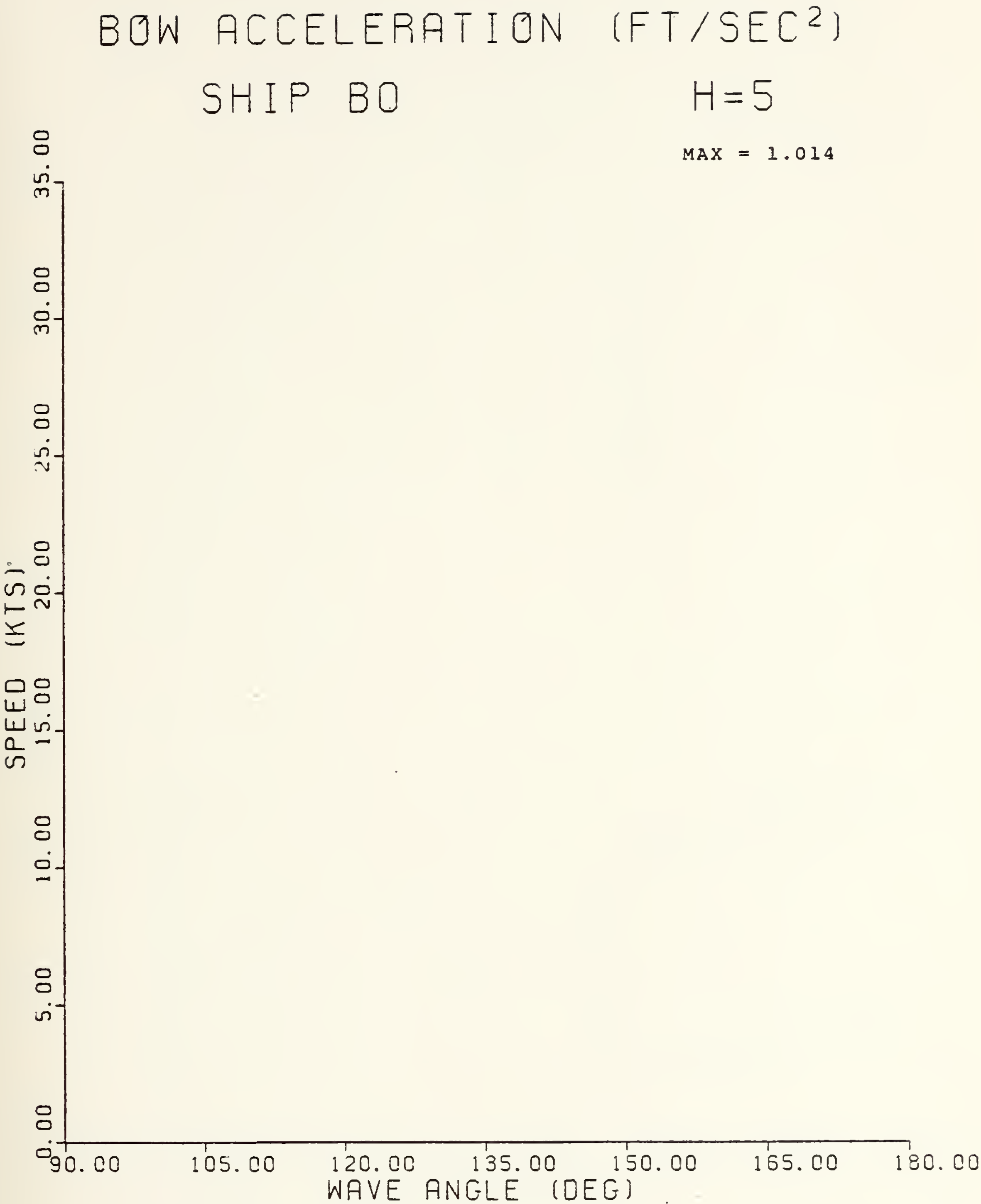
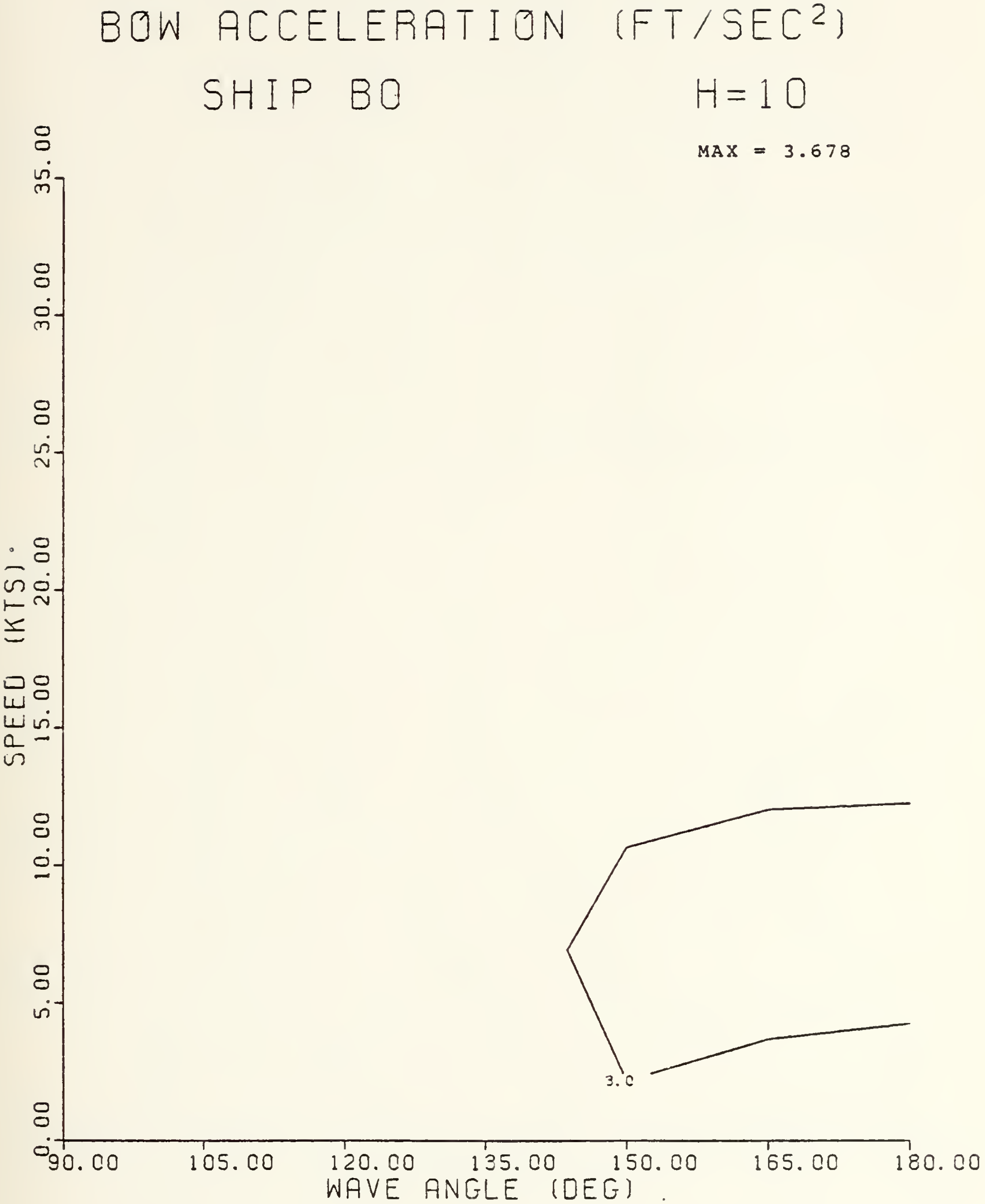
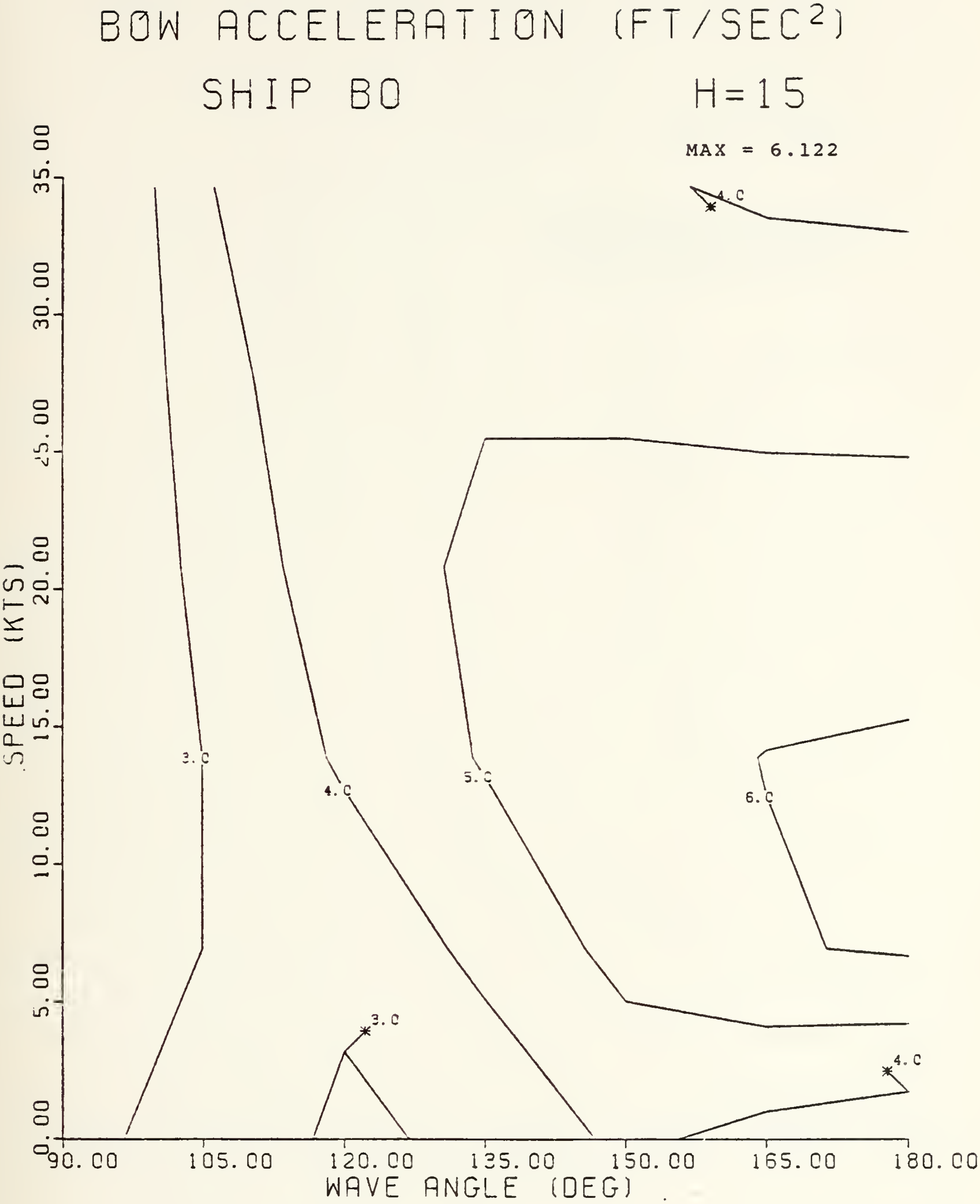


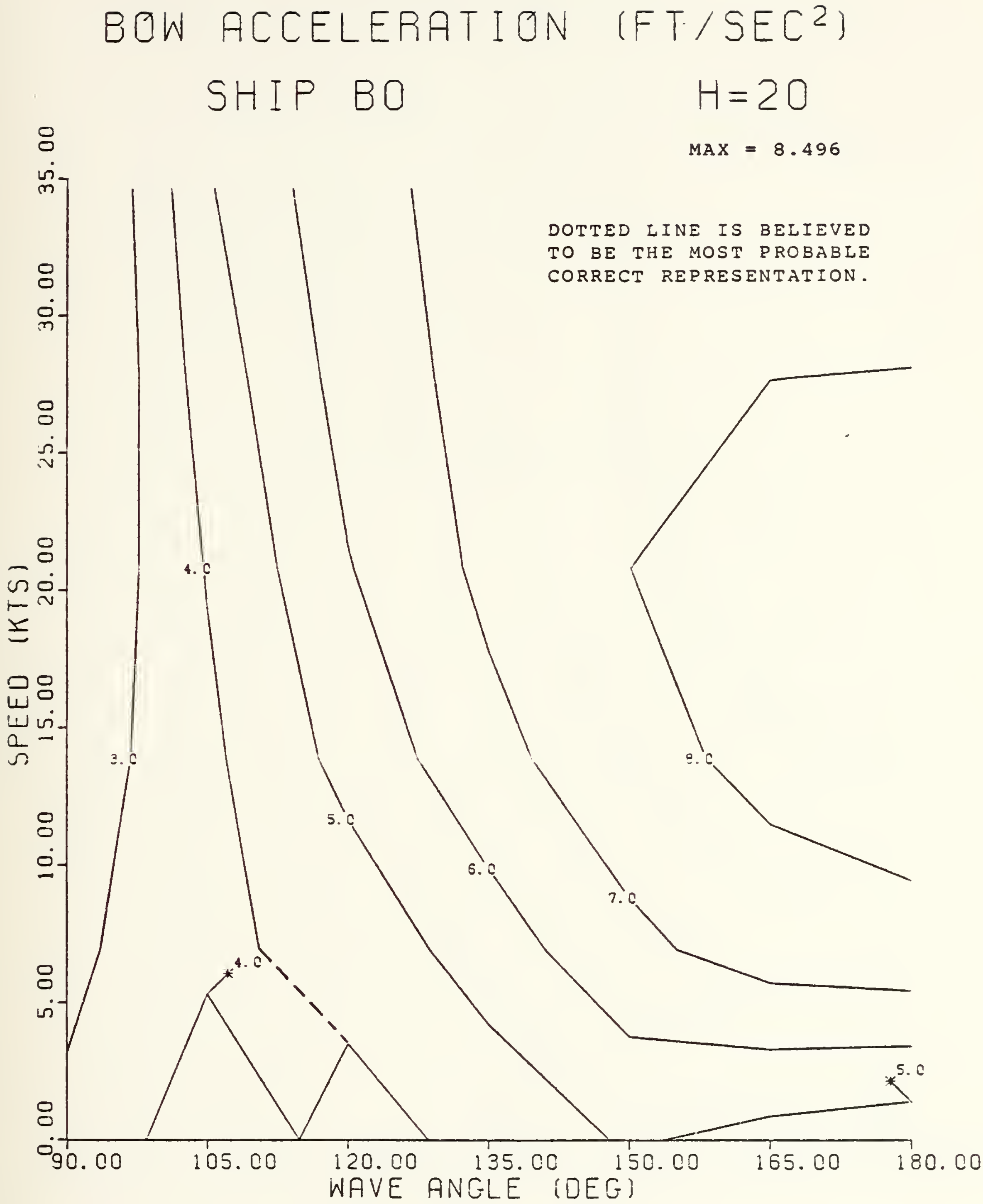
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC




BØW ACCELERATIØN (FT/SEC²)
SHIP BO
H=5
MAX = 1.014
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BØW ACCELERATIØN (FT/SEC²)
SHIP BO
H=10
MAX = 3.678
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
3.0


BOW ACCELERATION (FT/SEC²)
SHIP B0
H=15
MAX = 6.122
4.C
3.C
4.C
5.C
6.C
3.C
4.C
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW ACCELERATION (FT/SEC²)
SHIP BO
H=20
MAX = 8.496
DOTTED LINE IS BELIEVED
TO BE THE MOST PROBABLE
CORRECT REPRESENTATION.
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
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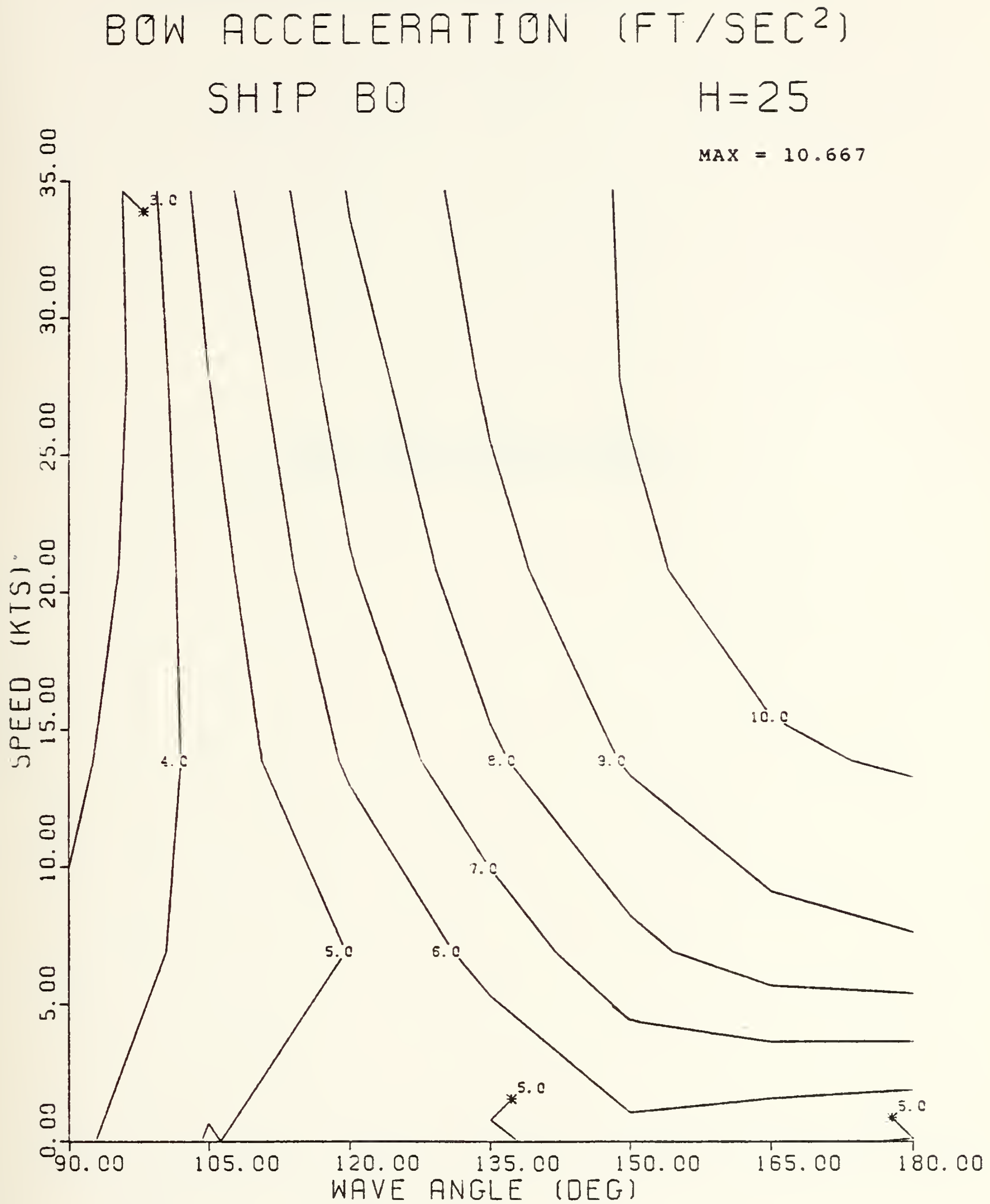
7.0
8.0
5.0

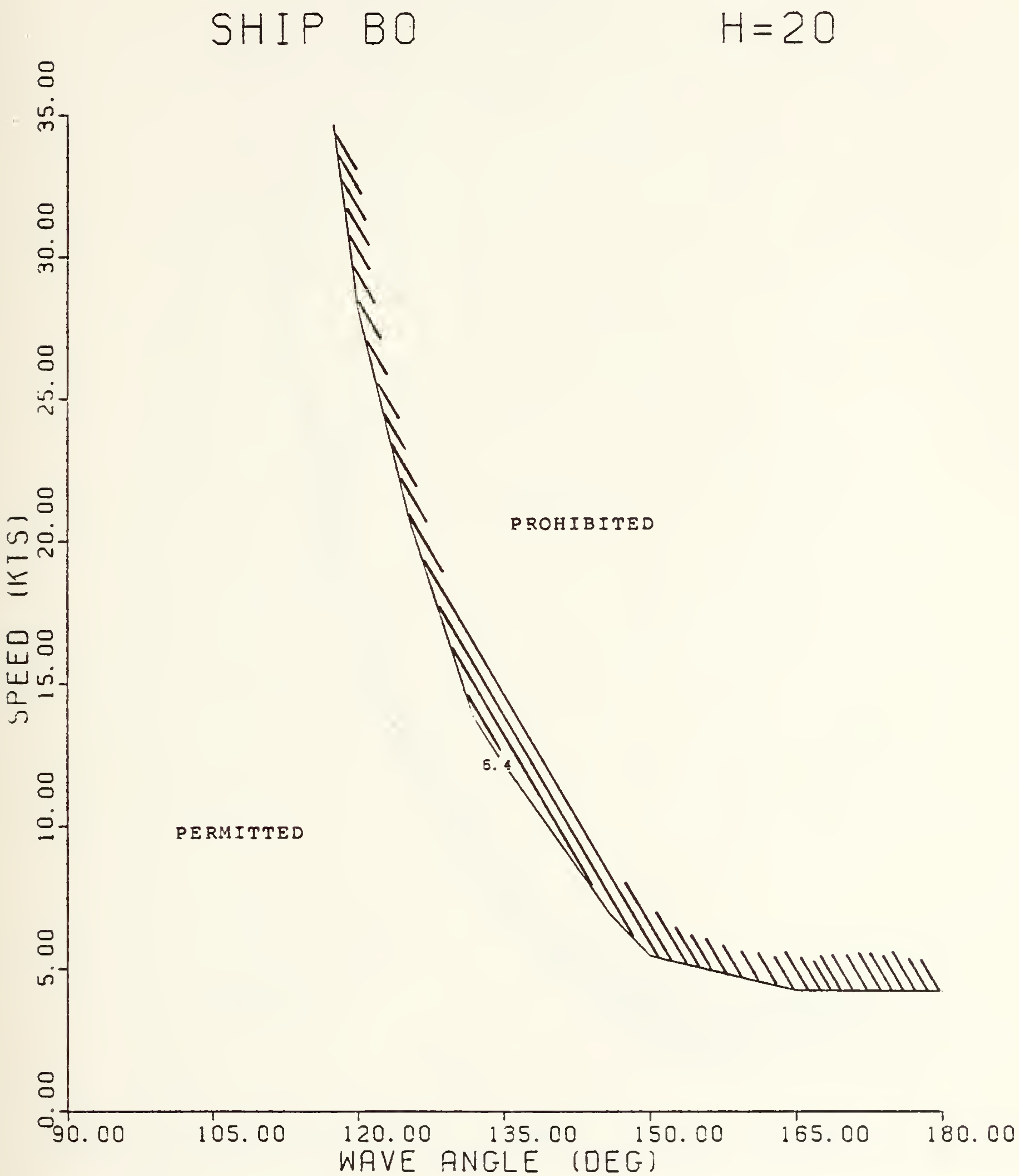

BOW ACCELERATION (FT/SEC²)
SHIP B0
H=25
MAX = 10.667
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
5.0
5.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

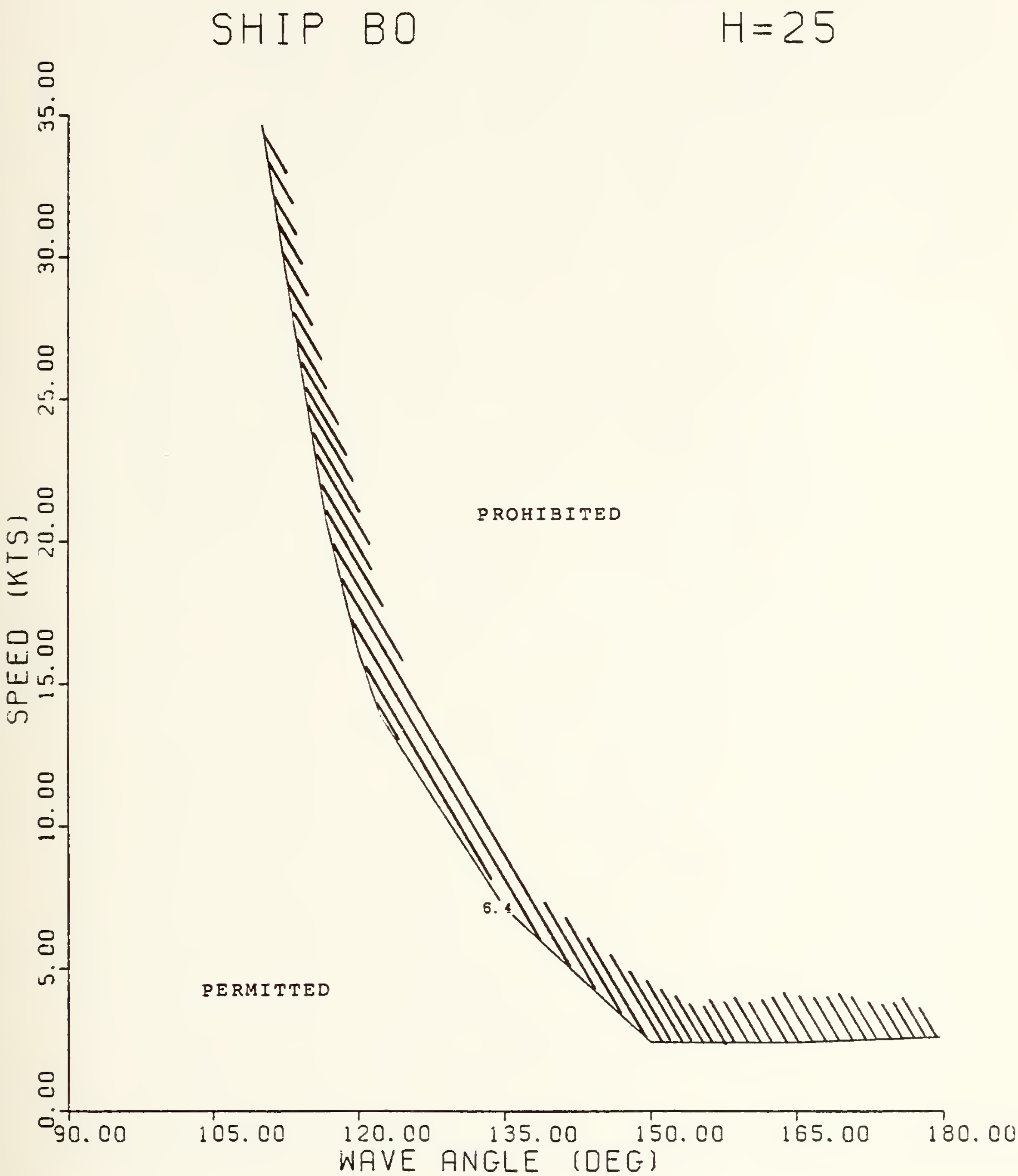
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

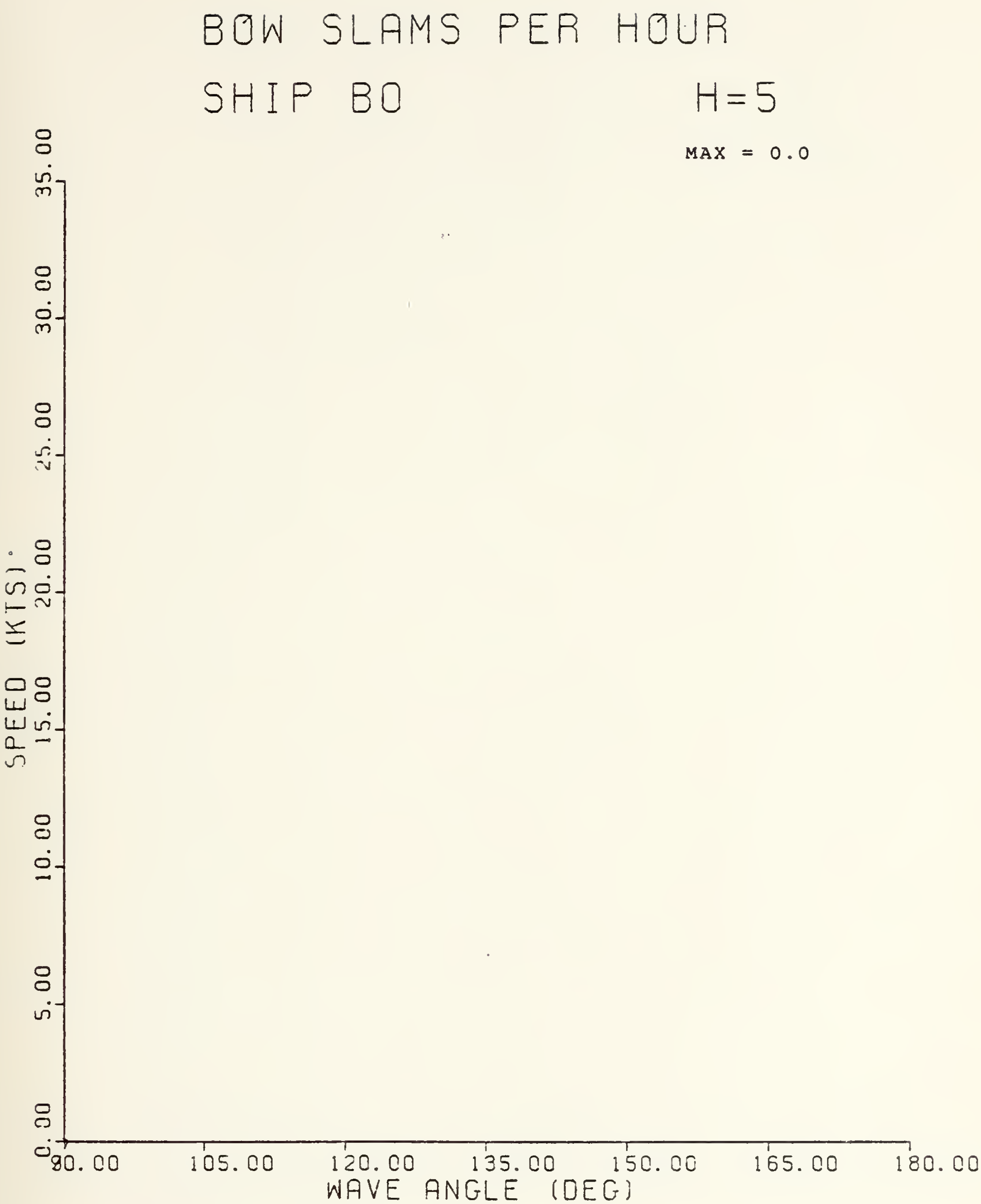
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

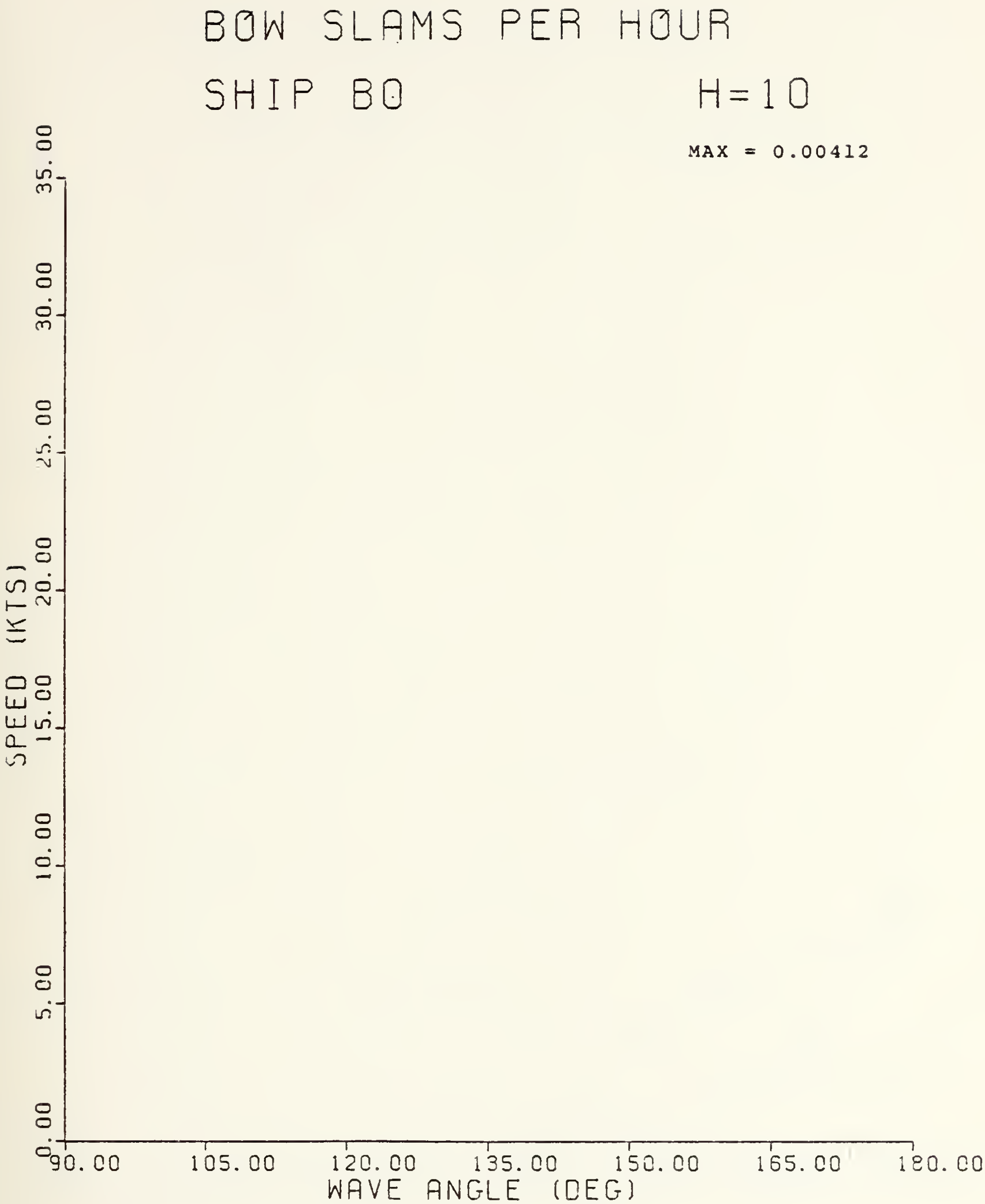
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

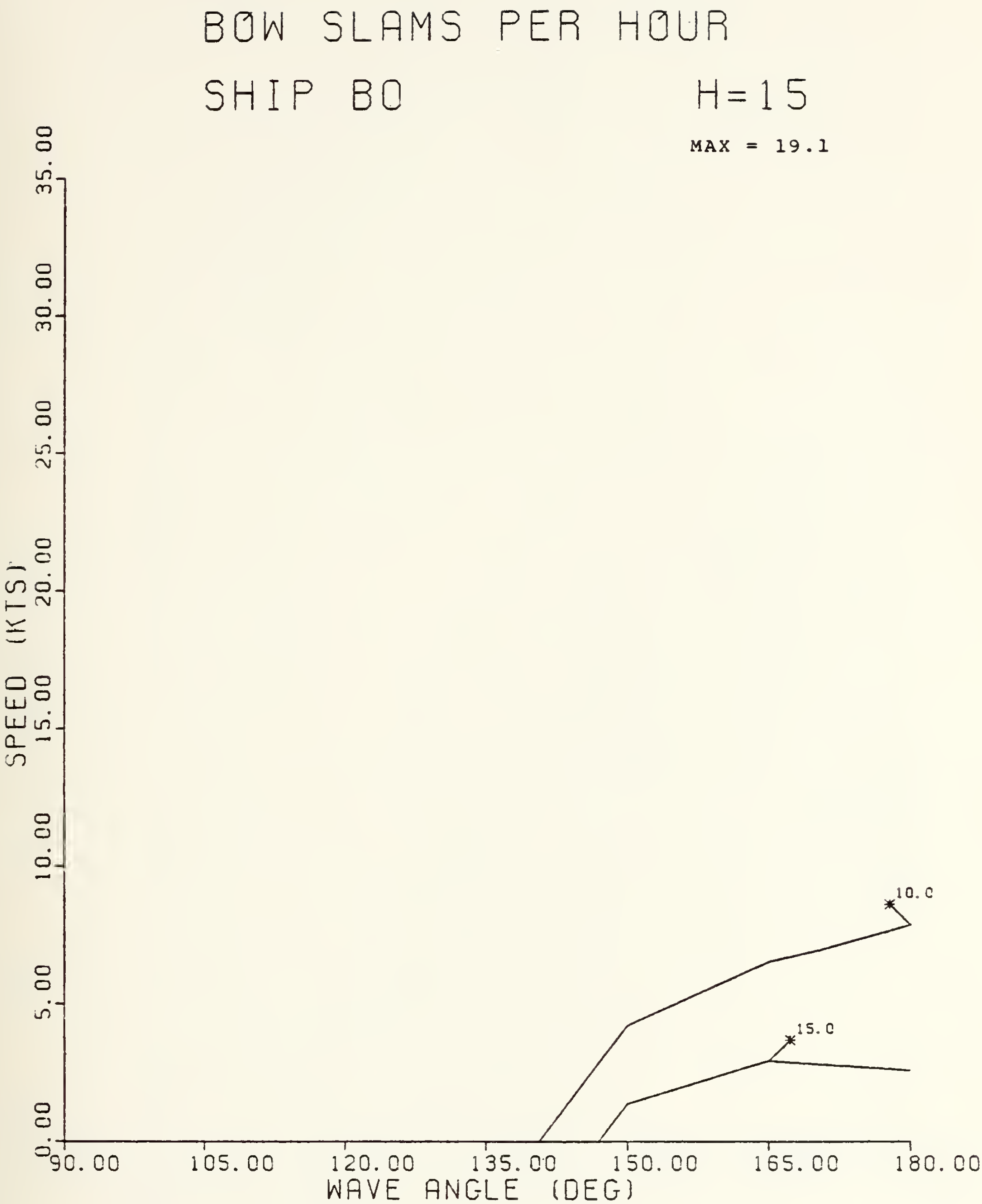


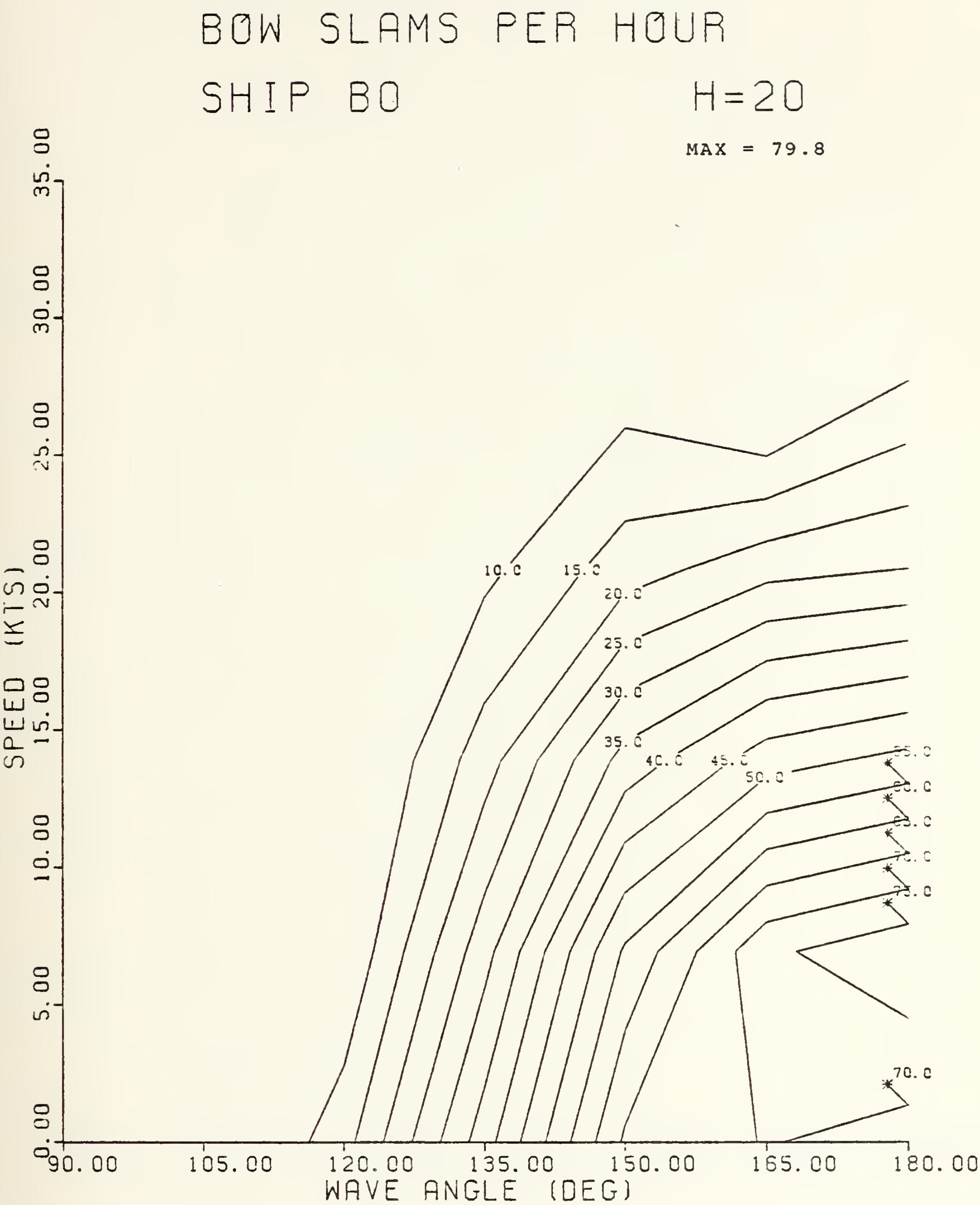
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

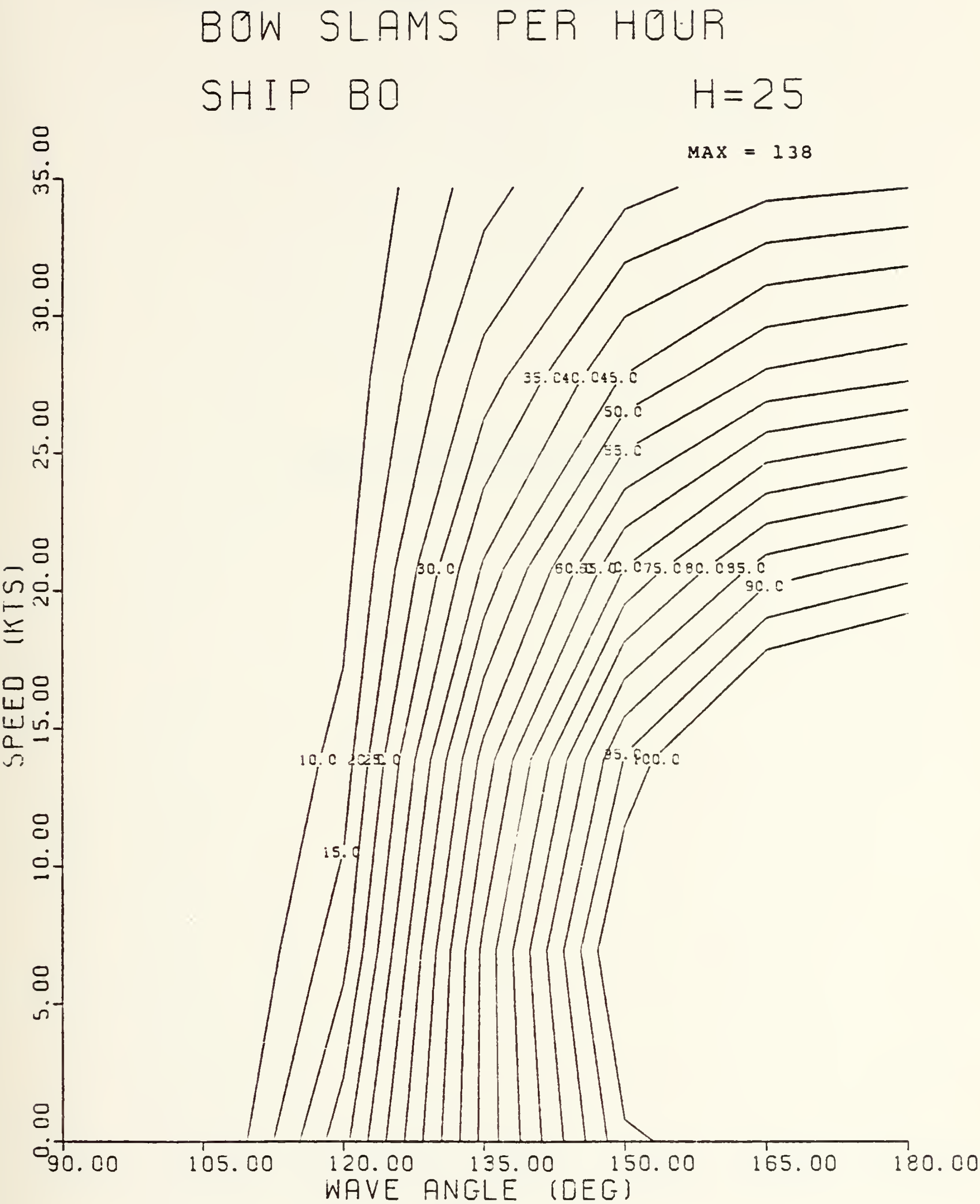



BOW SLAMS PER HOUR
SHIP BO
H=5
MAX = 0.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW SLAMS PER HOUR
SHIP BO
H=10
MAX = 0.00412
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW SLAMS PER HOUR
SHIP BO
H=15
MAX = 19.1
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
10.0
15.0


BØW SLAMS PER HØUR
SHIP BO
H=20
MAX = 79.8
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
70.0

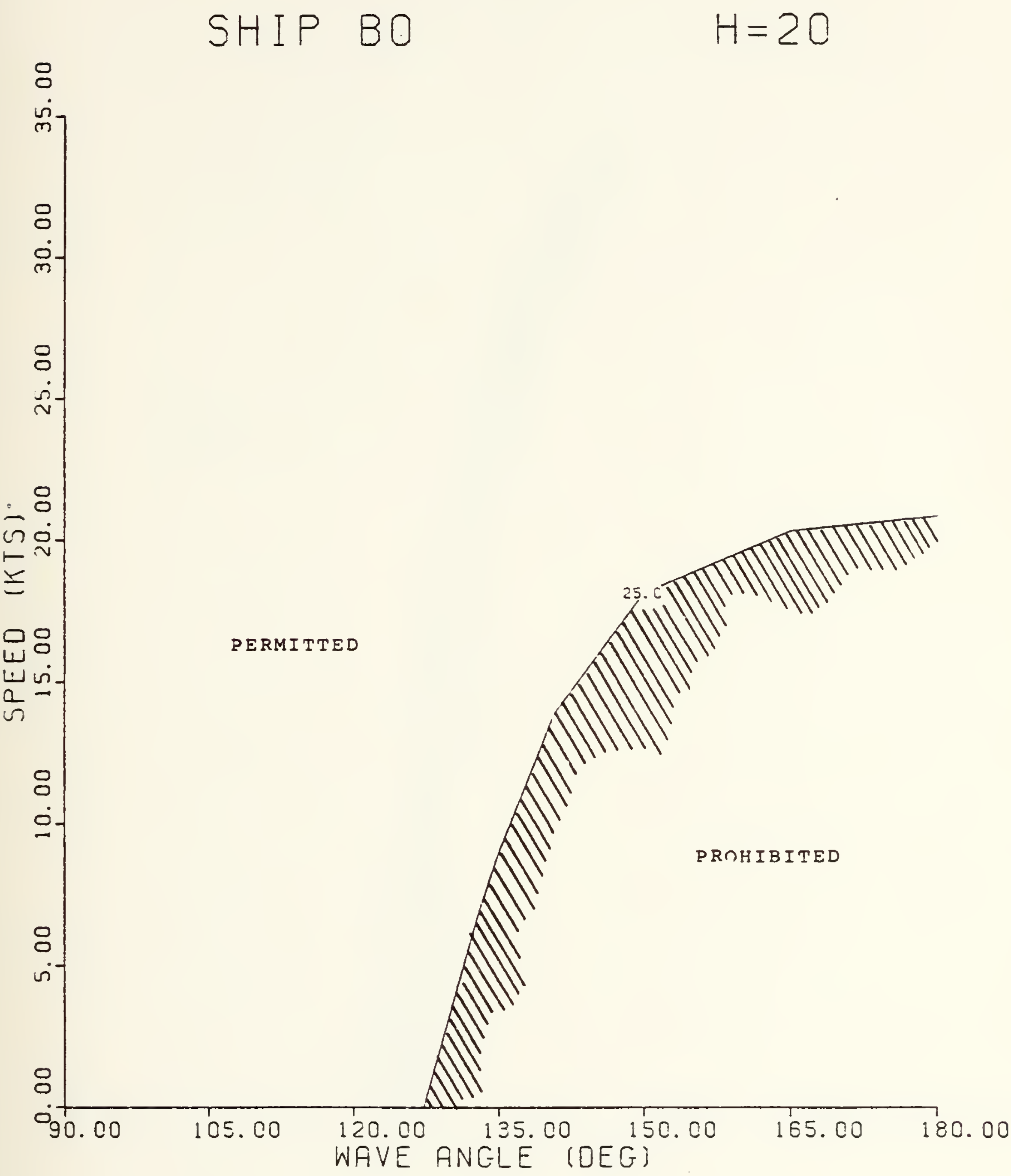

BØW SLAMS PER HOUR
SHIP BO
H=25
MAX = 138
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
30.0
35.0
40.0
45.0
50.0
55.0
75.0
80.0
85.0
90.0
95.0
100.0

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

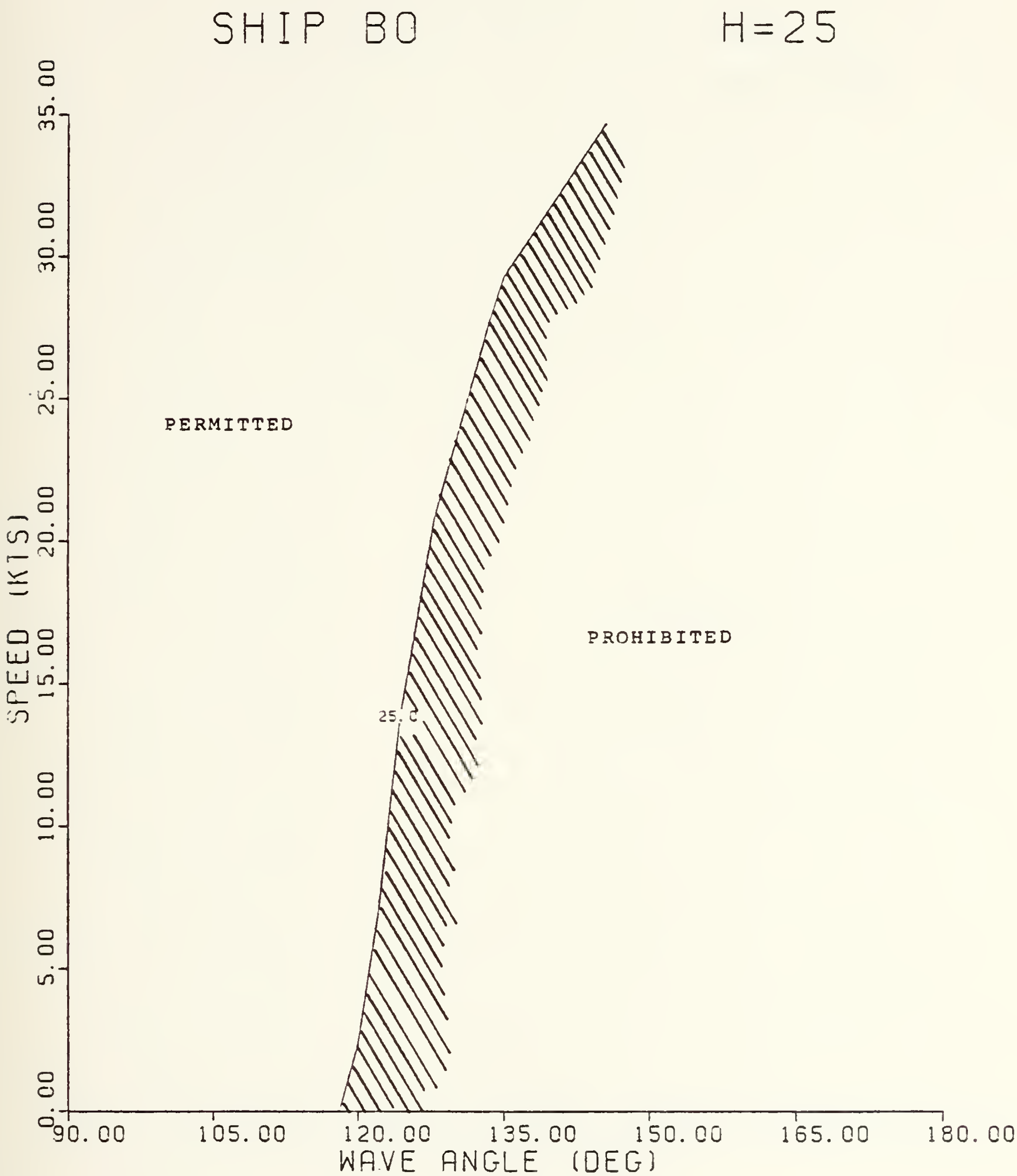
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR



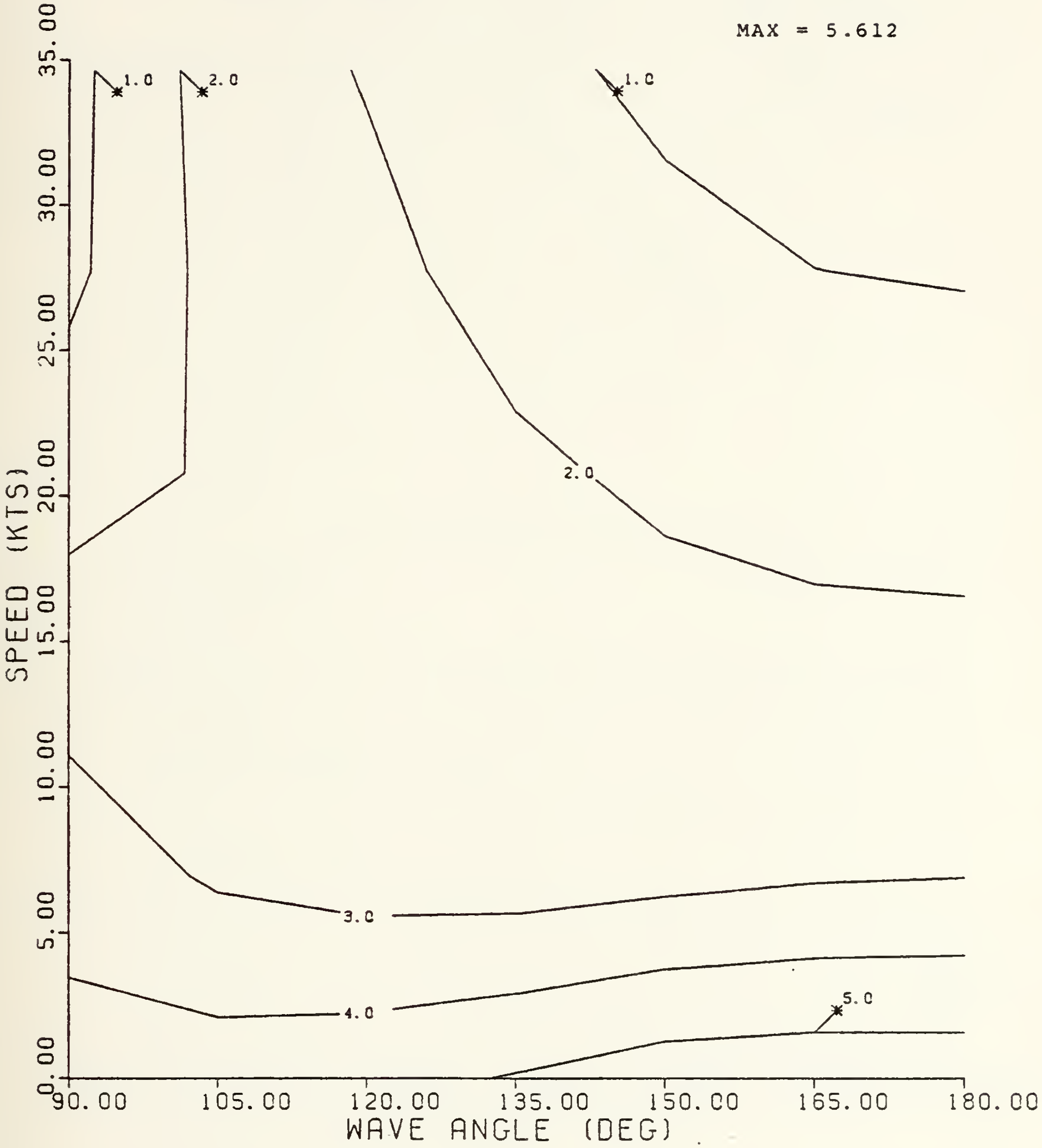
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

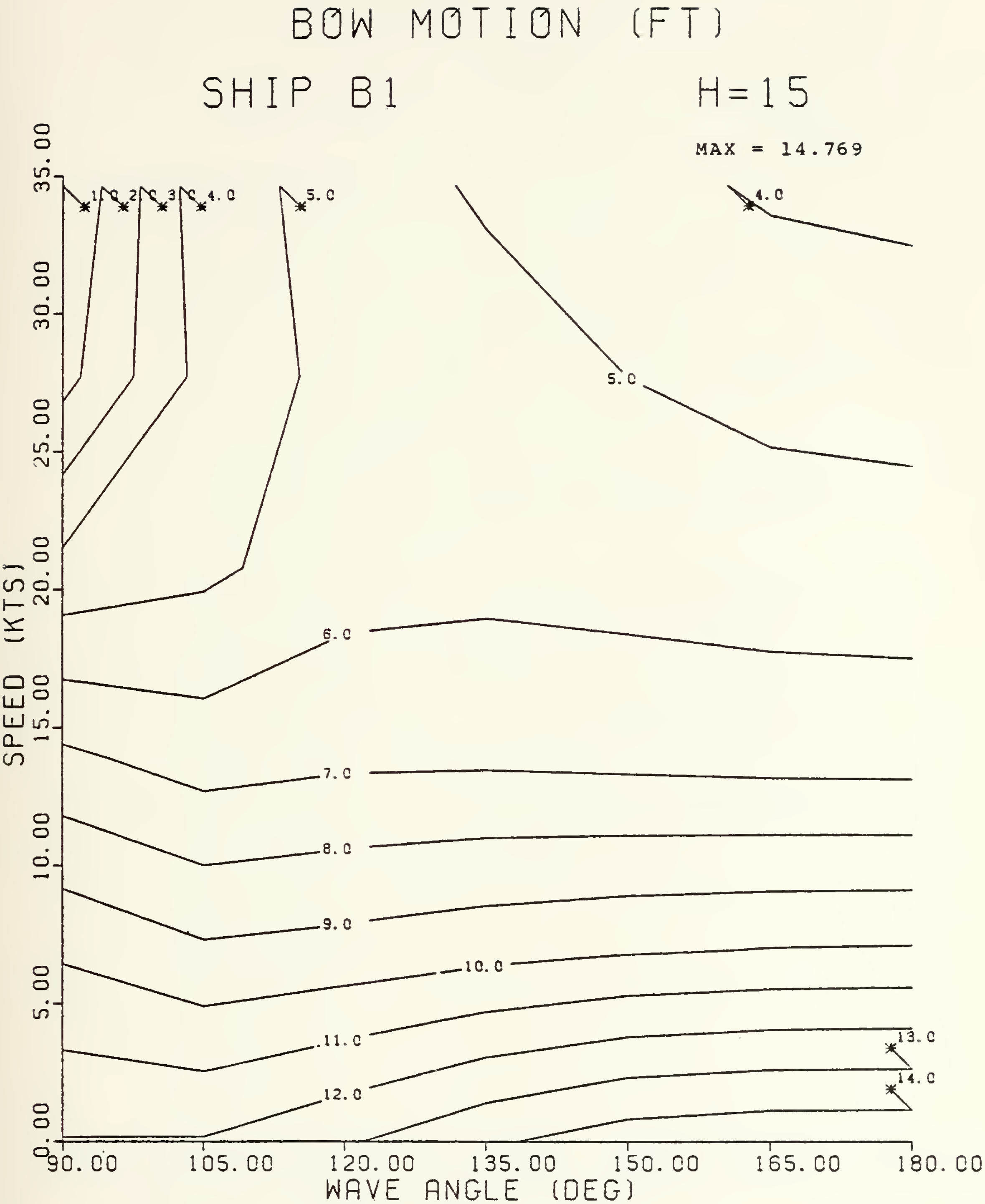


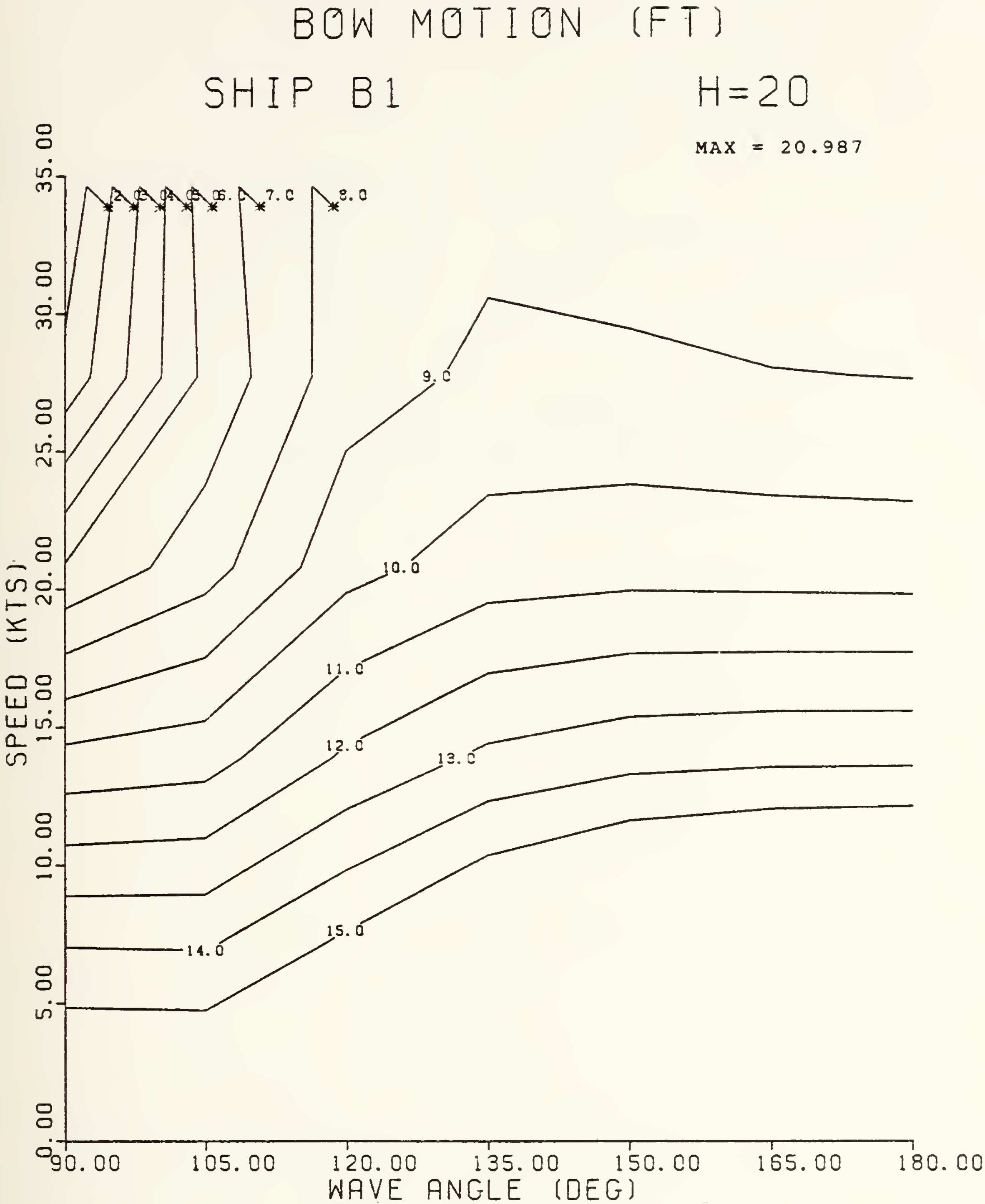

BØW MØTIØN (FT)
SHIP B1
H=5
MAX = 0.689
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

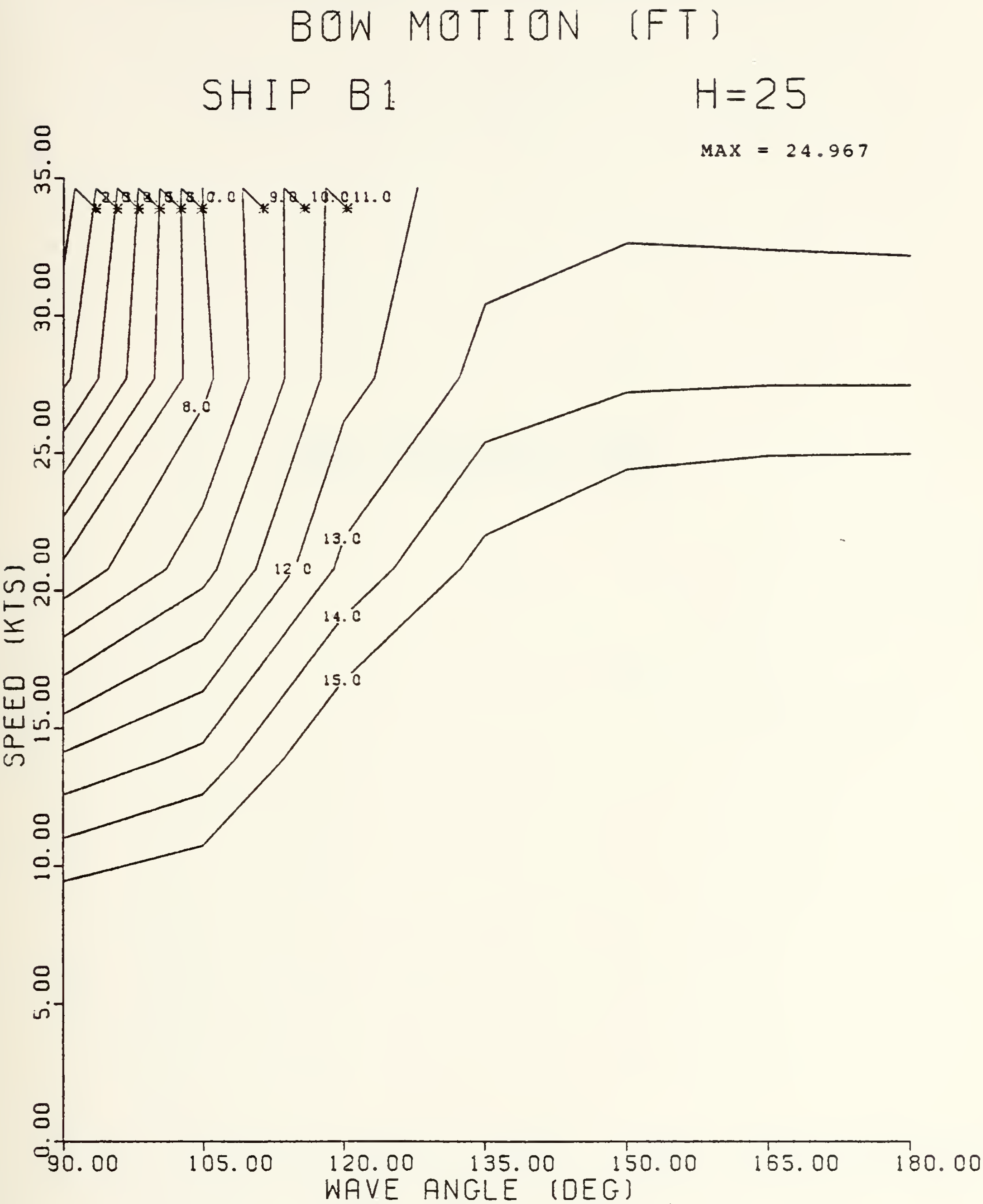
BOW MOTION (FT)

SHIP B1 H=10



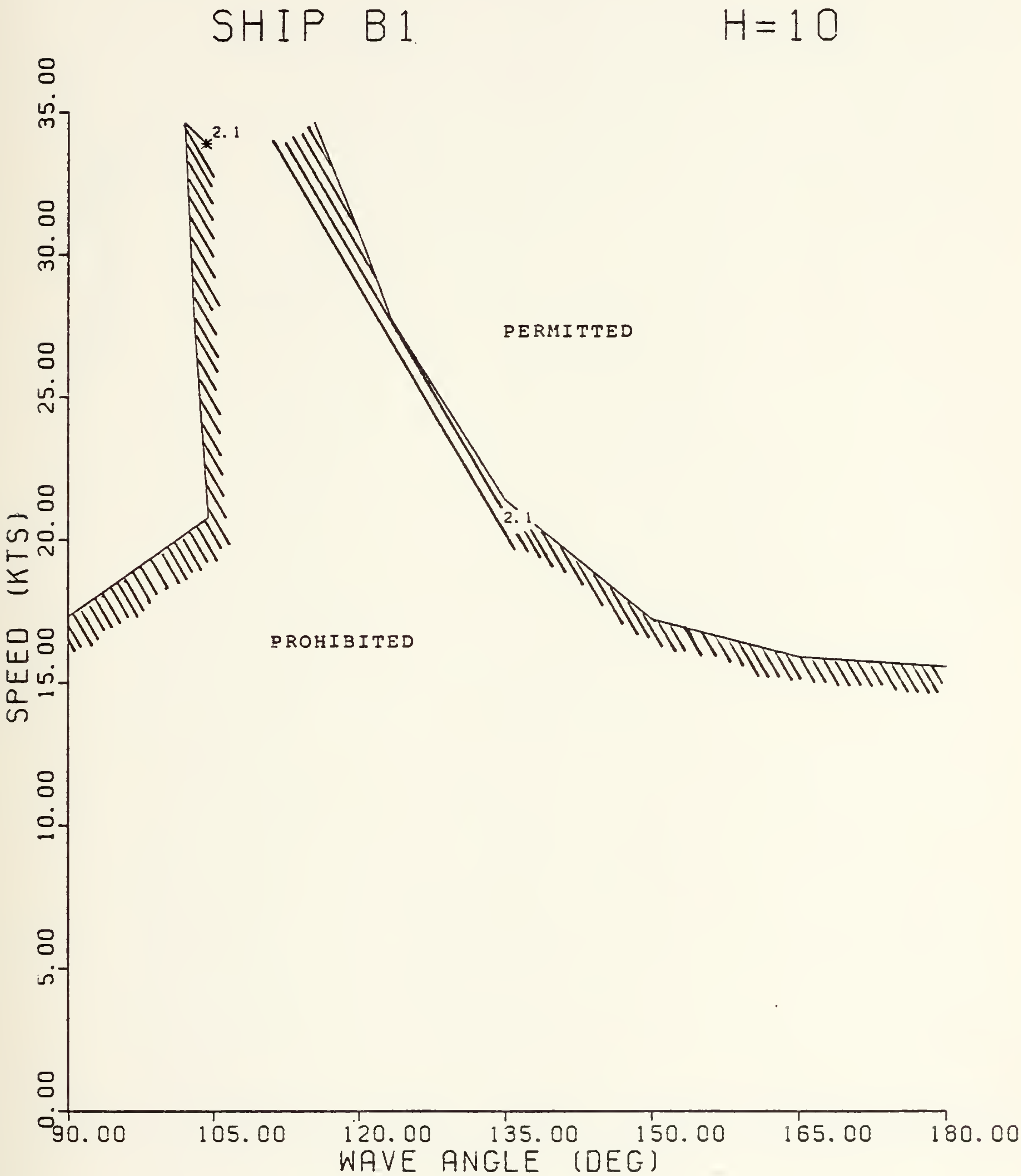

BOW MOTION (FT)
SHIP B1
H=15
MAX = 14.769
1.0
2.0
3.0
4.0
5.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW MOTION (FT)
SHIP B1
H=20
MAX = 20.987
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0

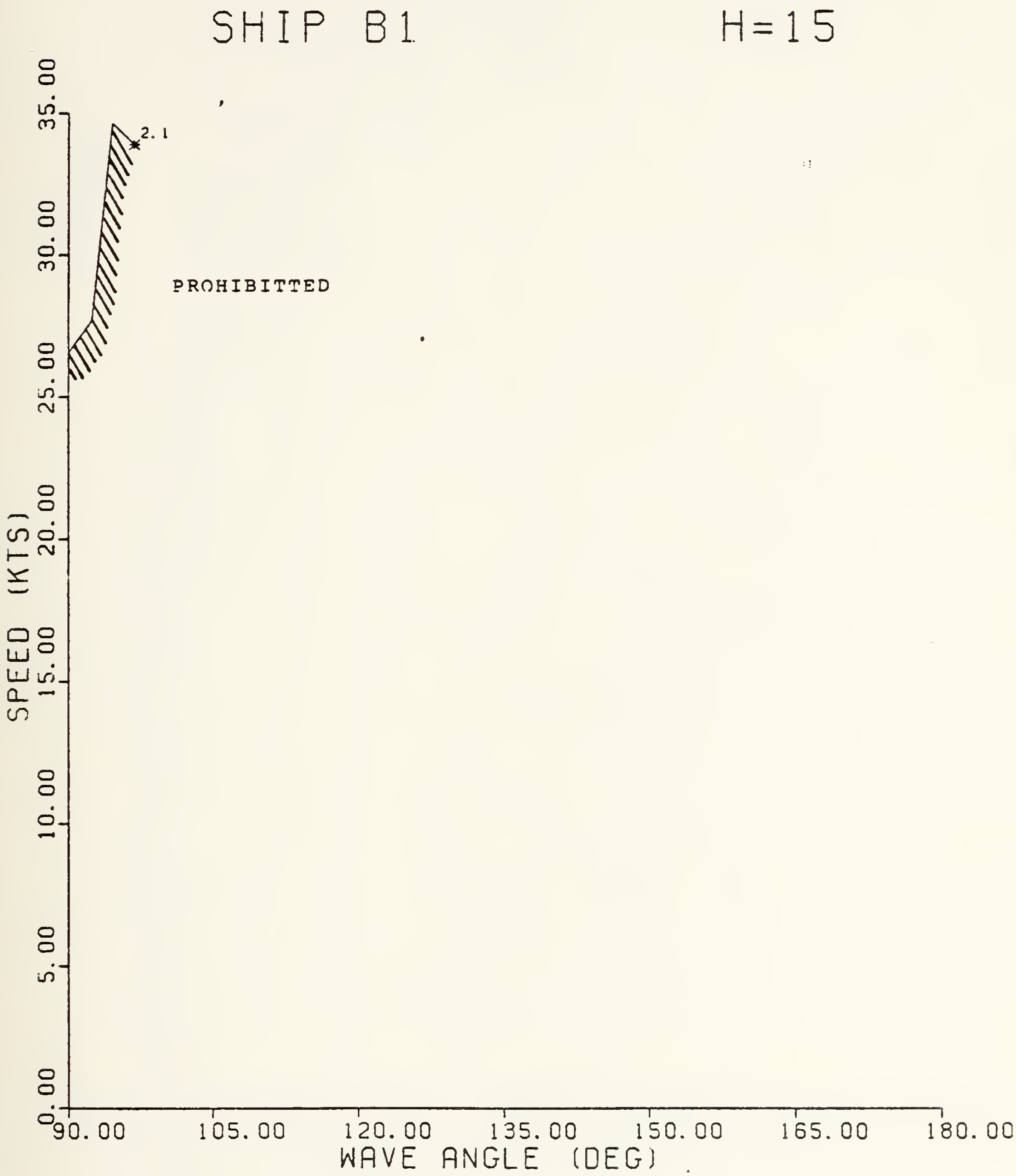

BOW MOTION (FT)
SHIP B1
H=25
MAX = 24.967
8.0
12.0
13.0
14.0
15.0
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

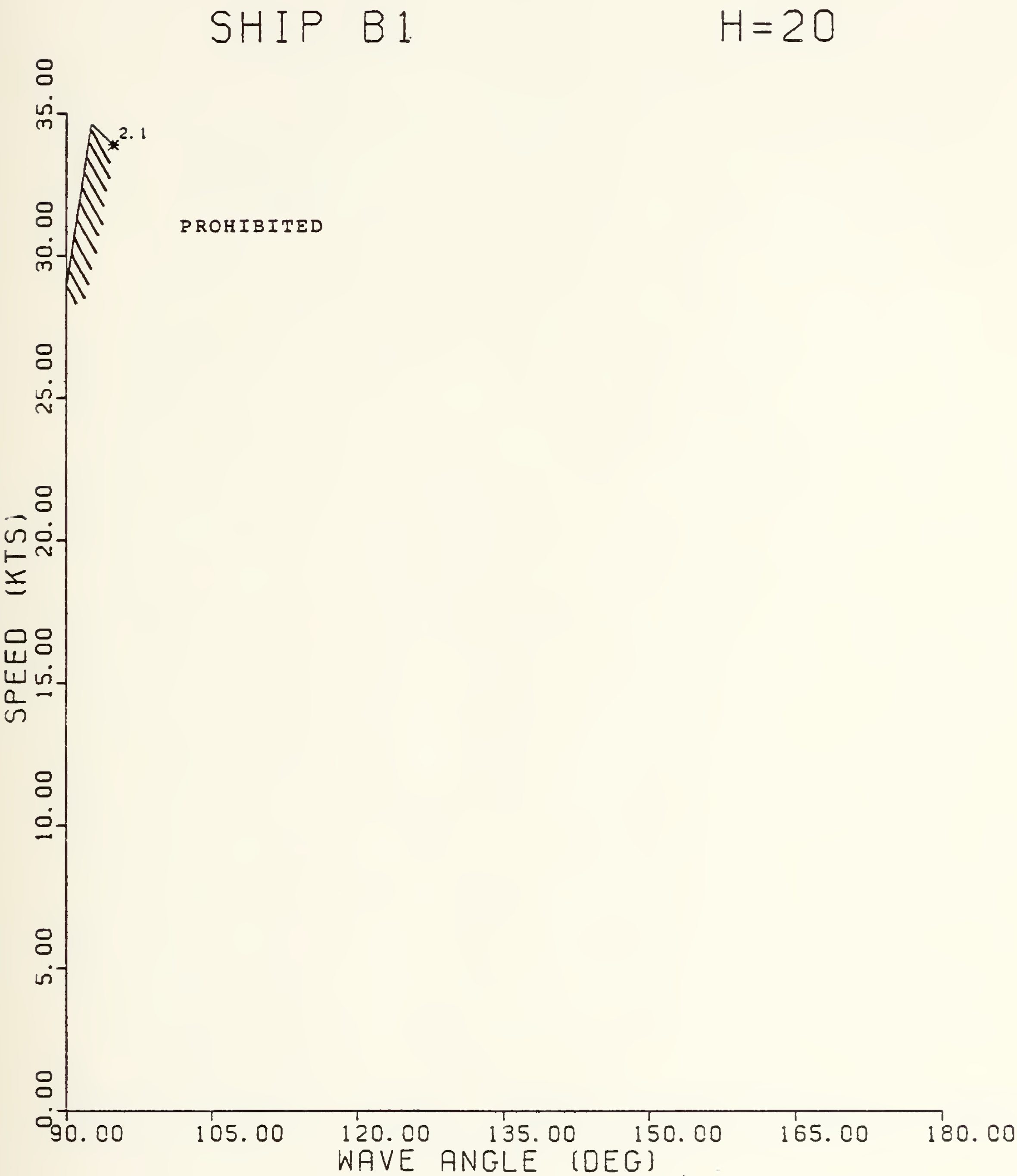
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET



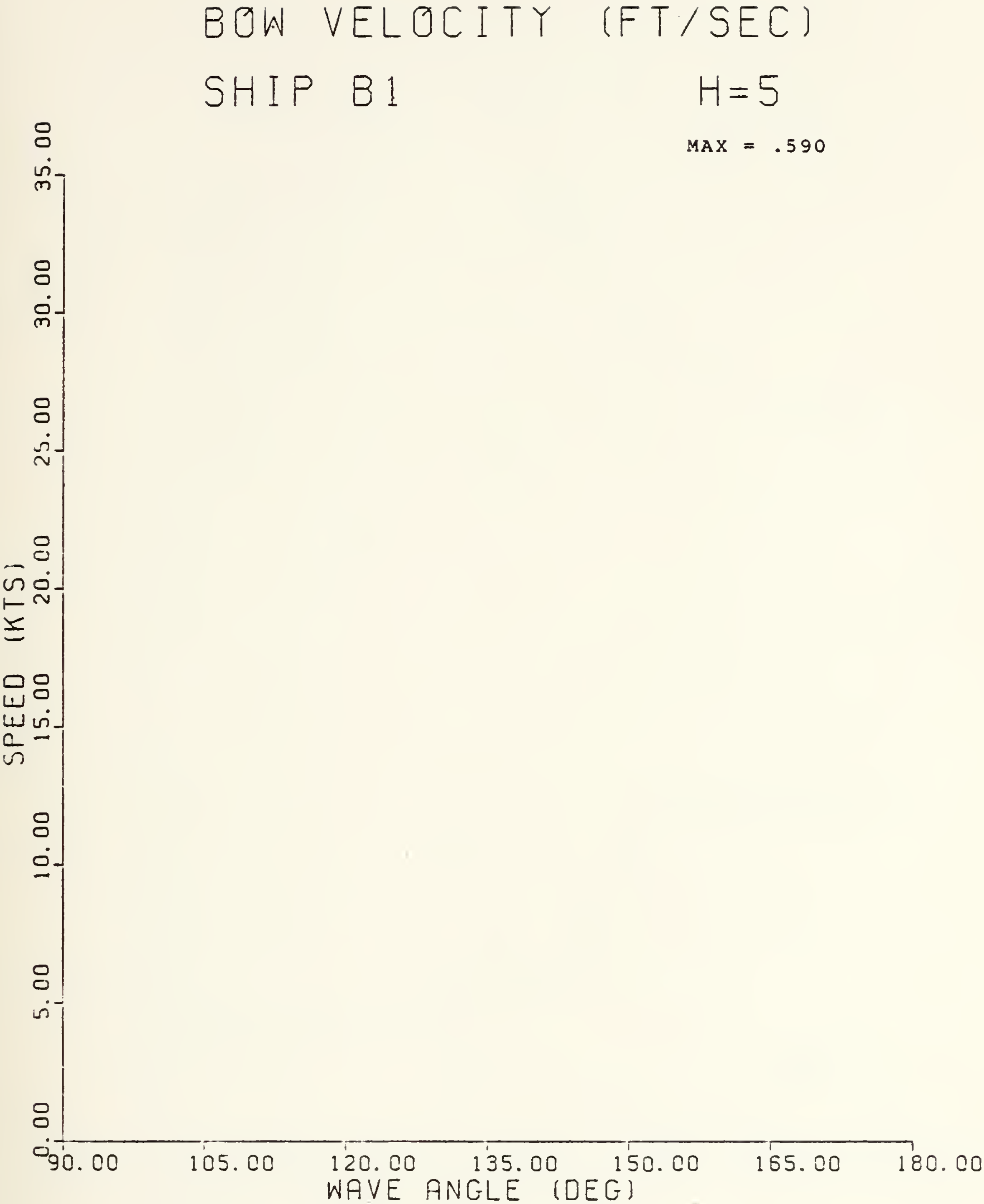
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

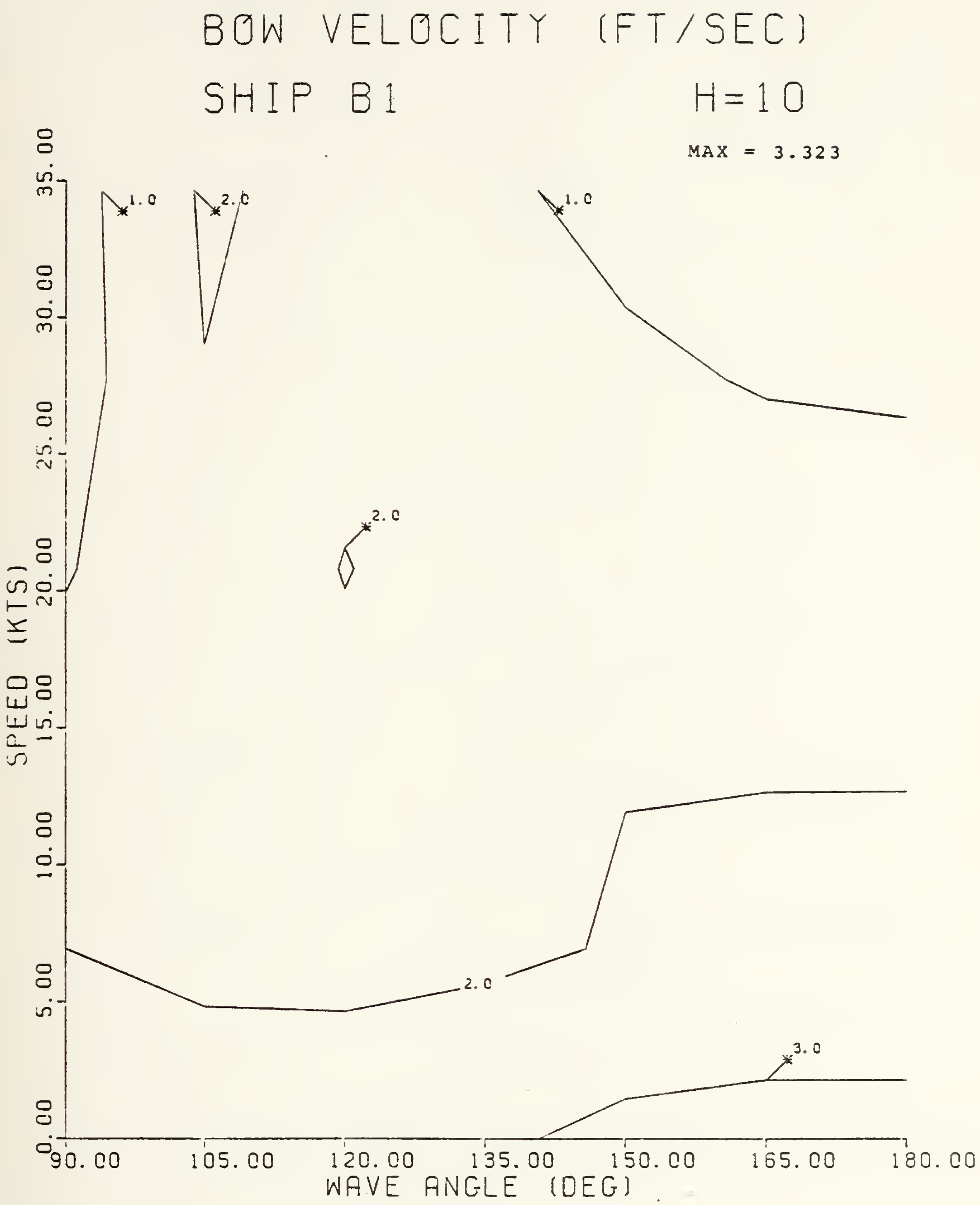


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET



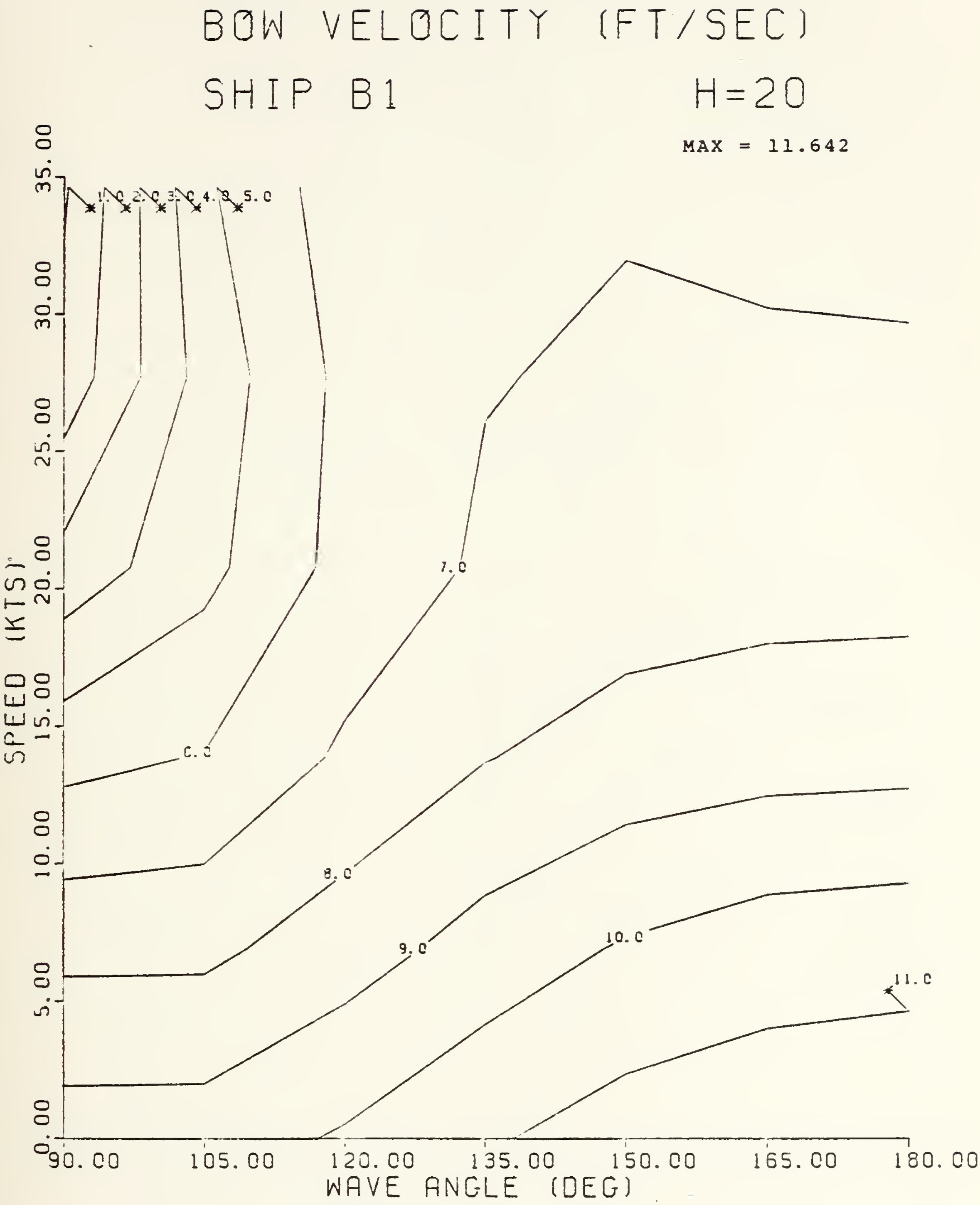
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET


BØW VELOCITY (FT/SEC)
SHIP B1
H=5
MAX = .590
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

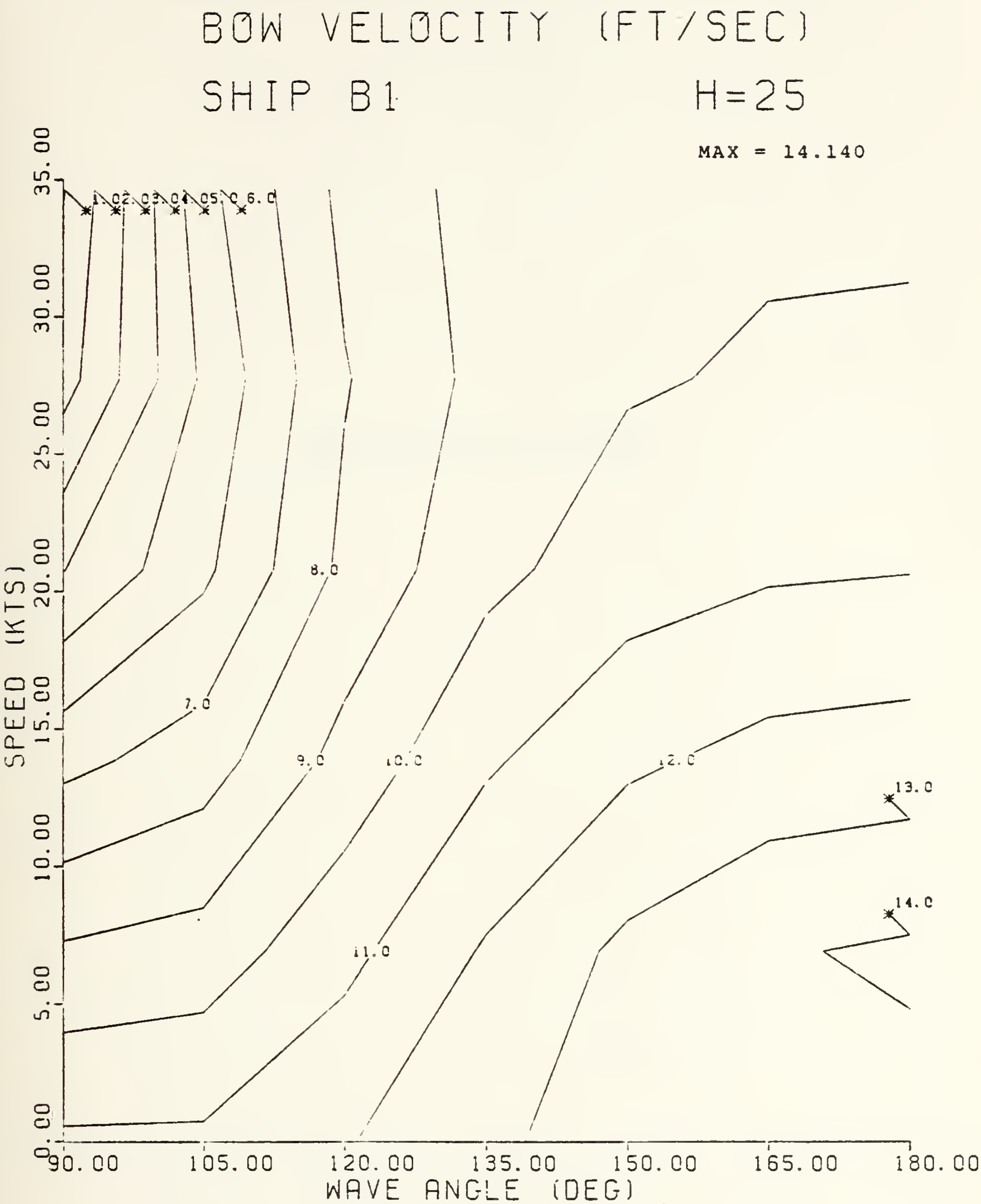

BØW VELØCITY (FT/SEC)
SHIP B1
H=10
MAX = 3.323
1.0
2.0
1.0
2.0
2.0
3.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

BØW VELØCITY (FT/SEC)

SHIP B1 H=15



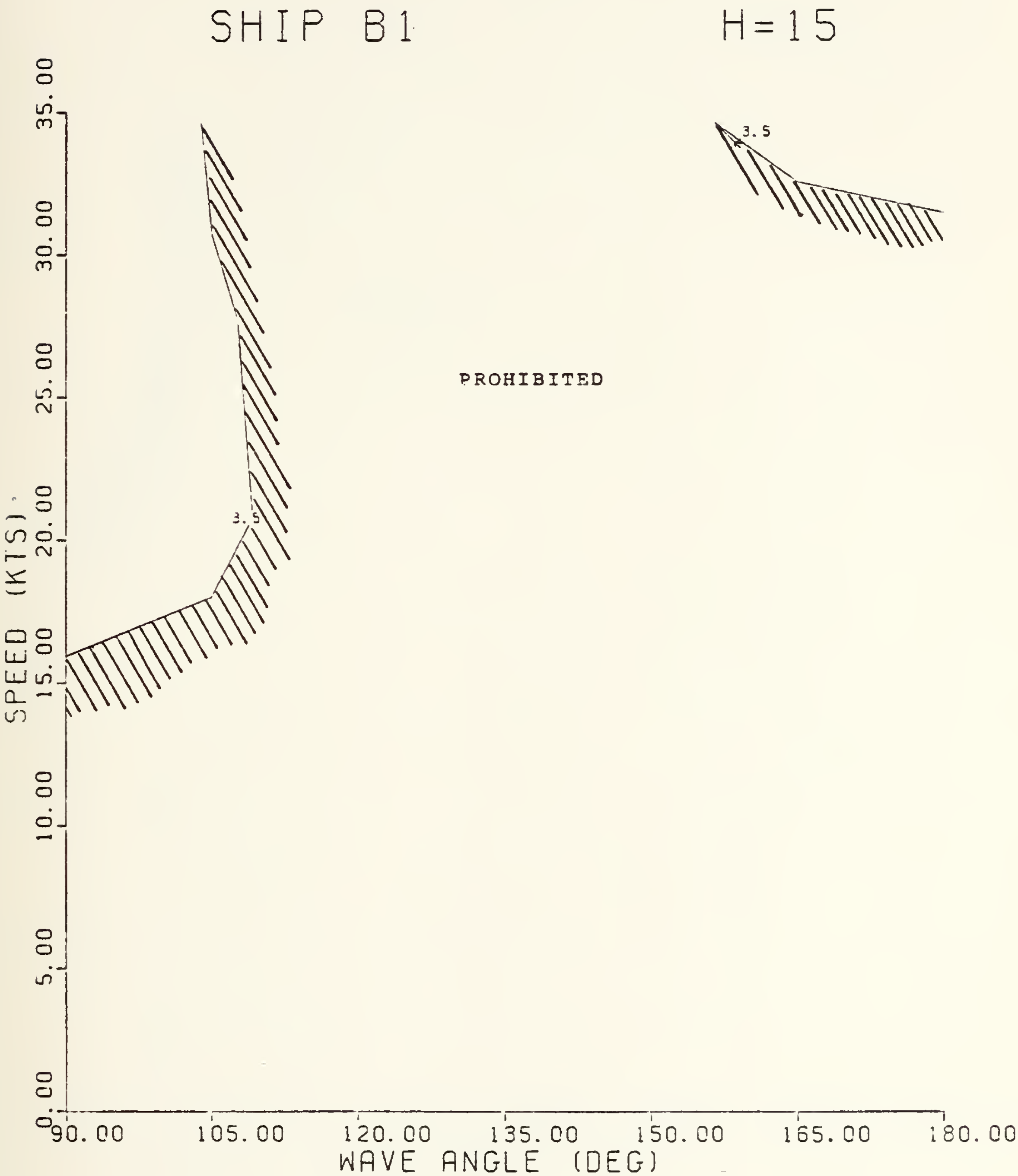
BØW VELØCITY (FT/SEC)
SHIP B1
H=20
MAX = 11.642
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
WAVE ANGLE (DEG)
90.00
105.00
120.00
135.00
150.00
165.00
180.00


BOW VELOCITY (FT/SEC)
SHIP B1 H=25
MAX = 14.140
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0

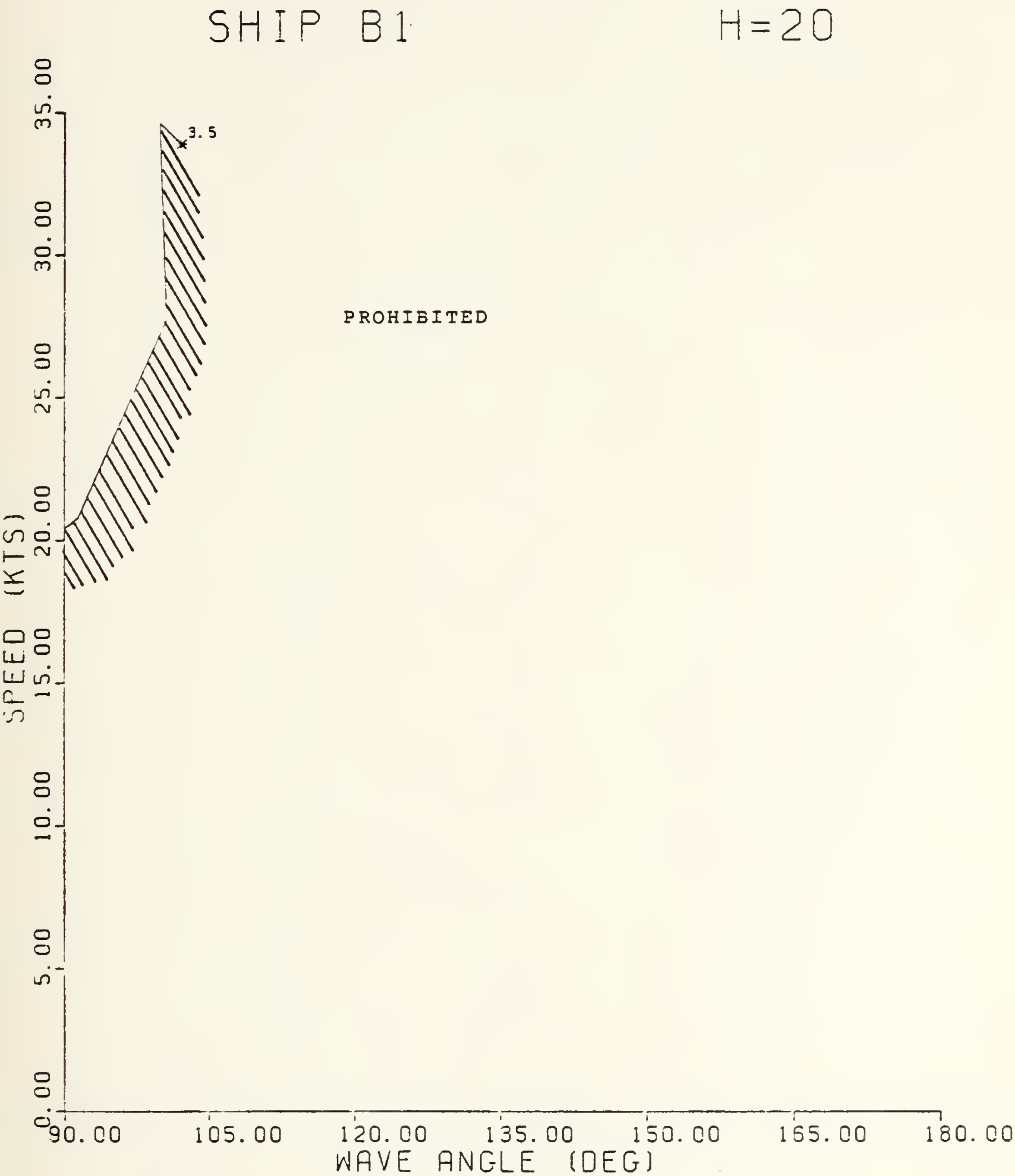
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

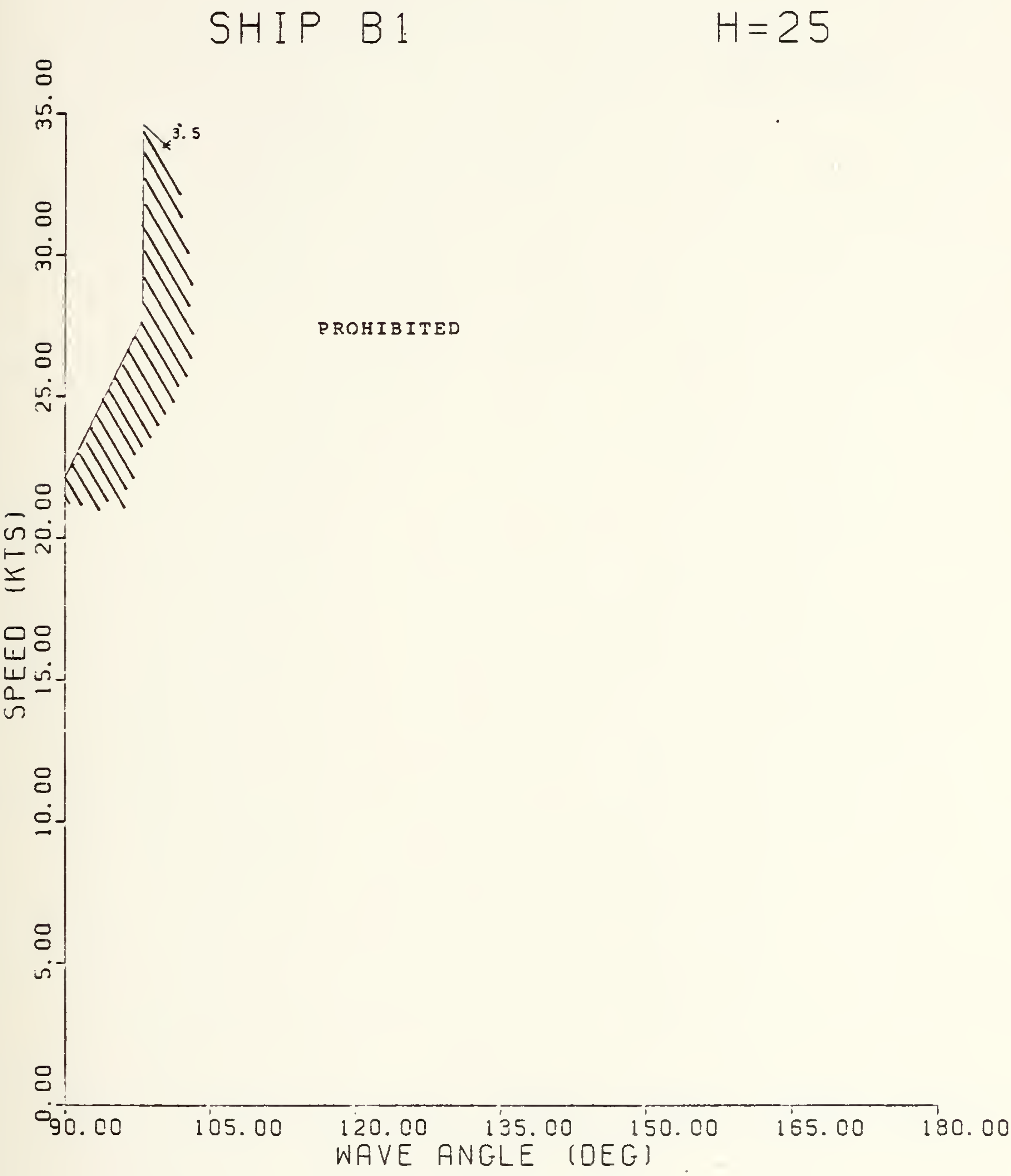
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC



OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

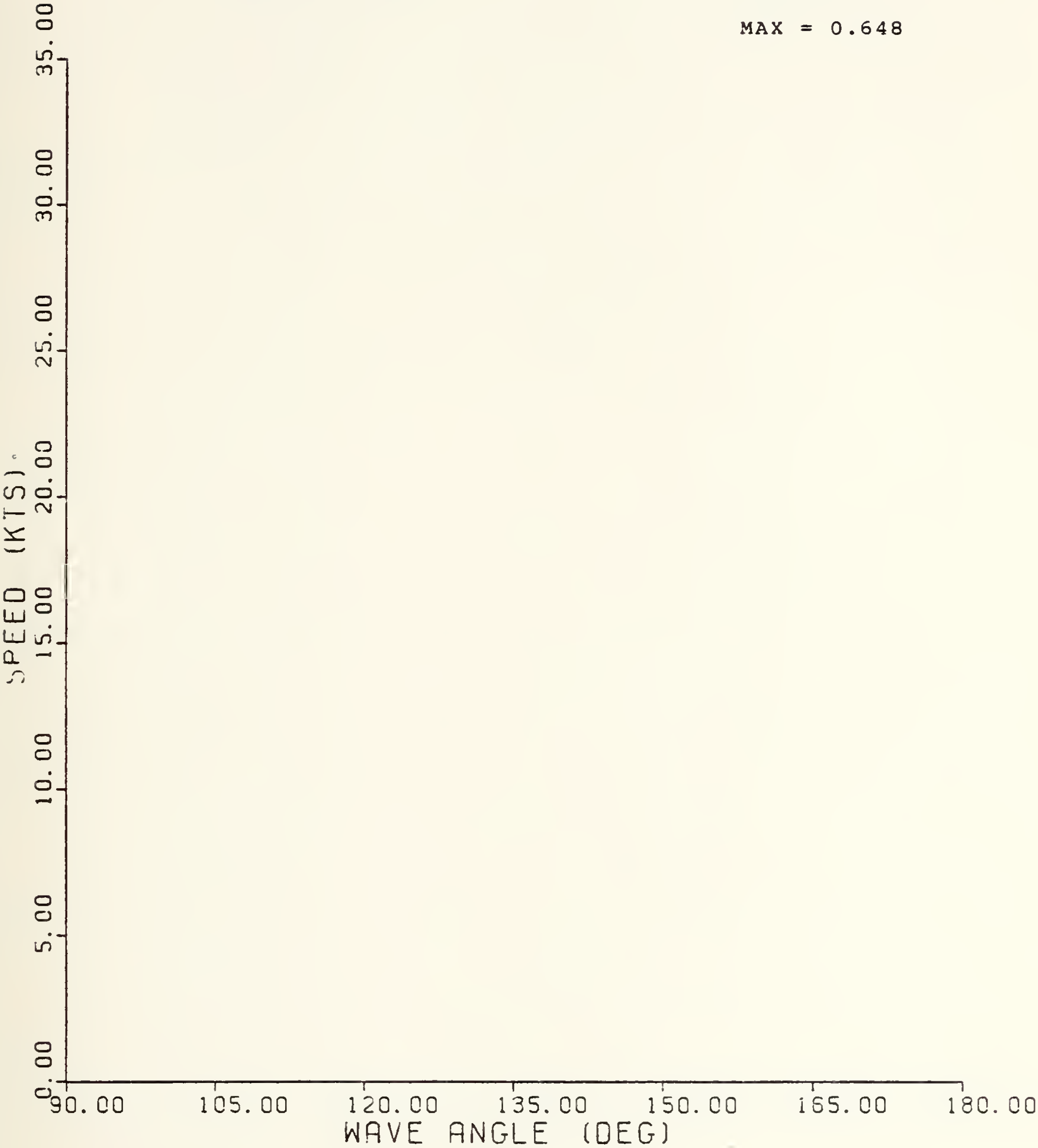


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC



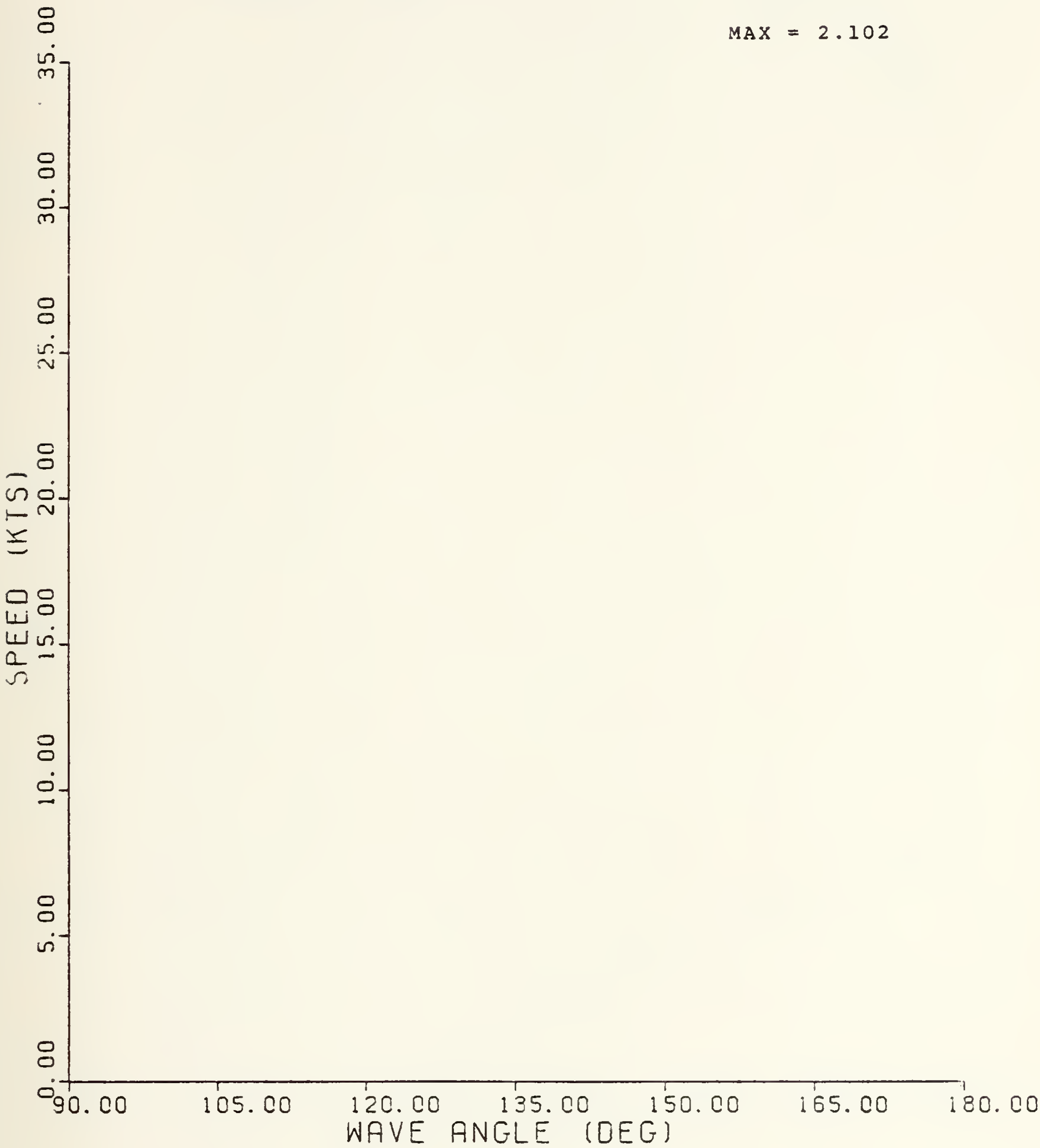
BOW ACCELERATION (FT/SEC^2)

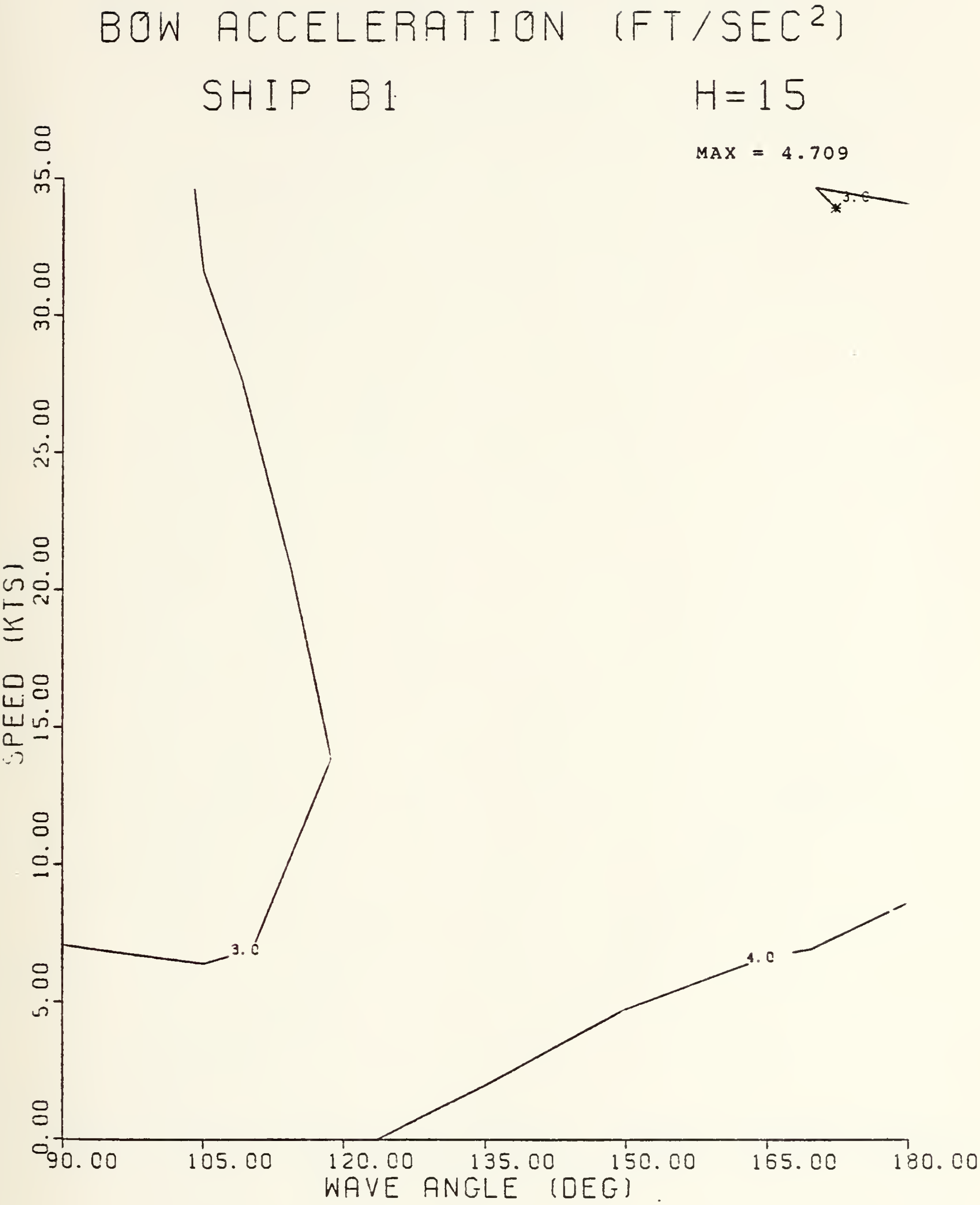
SHIP B1 H=5

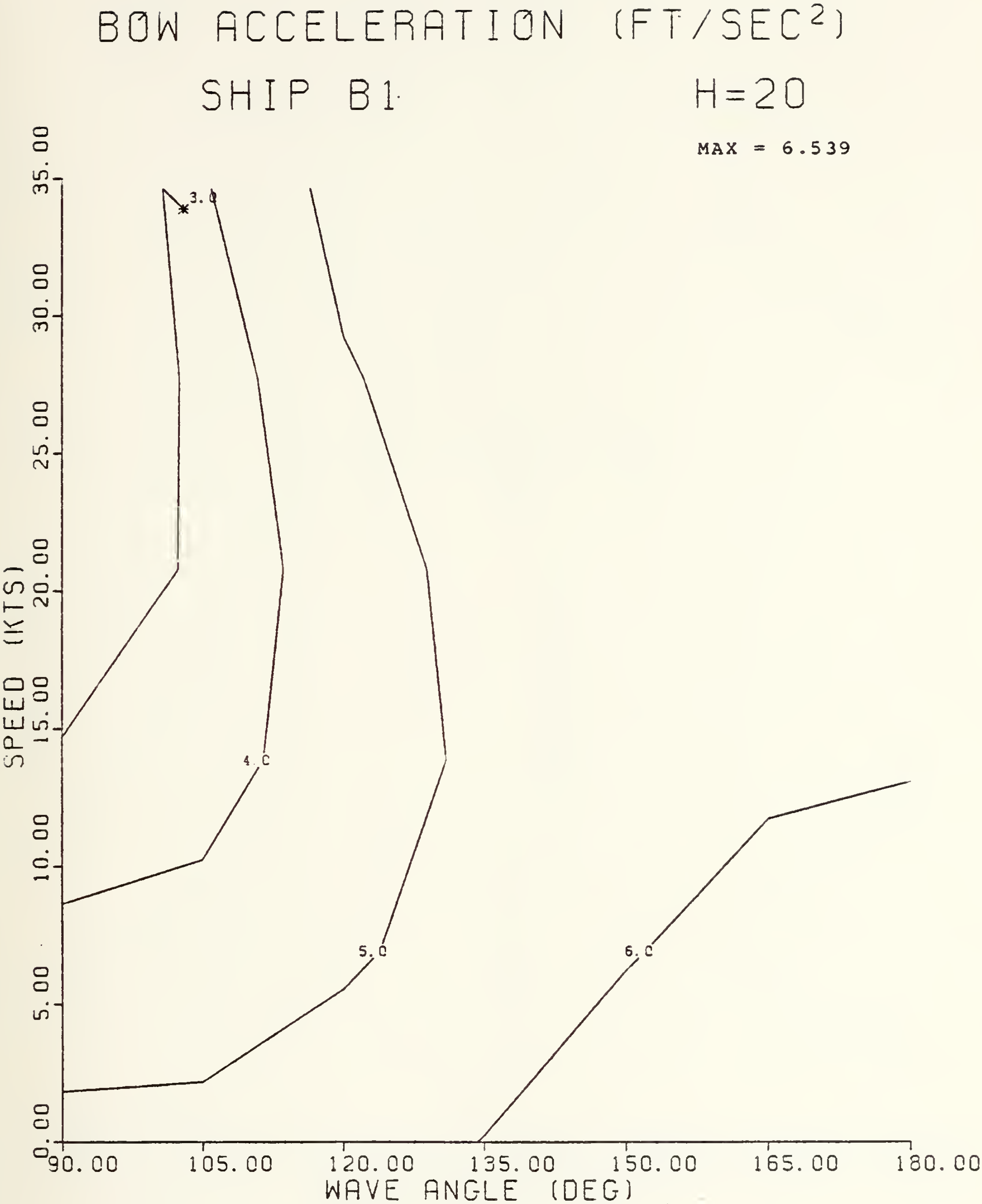


BOW ACCELERATION (FT/SEC^2)

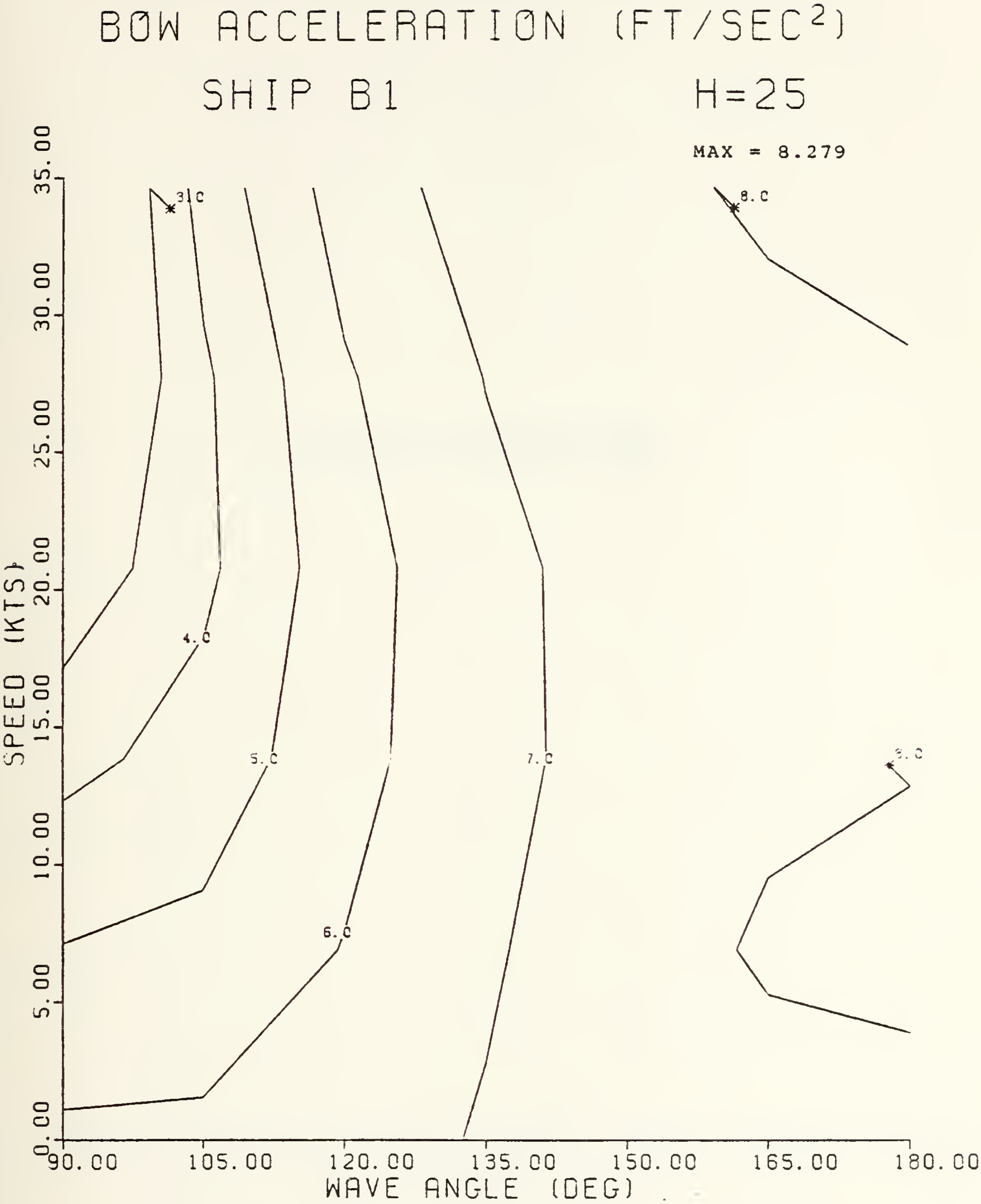
SHIP B1 H=10




BØW ACCELERATIØN (FT/SEC²)
SHIP B1
H=15
MAX = 4.709
3.0
3.0
4.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BOW ACCELERATION (FT/SEC2)
SHIP B1
H=20
MAX = 6.539
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
3.0
4.0
5.0
6.0



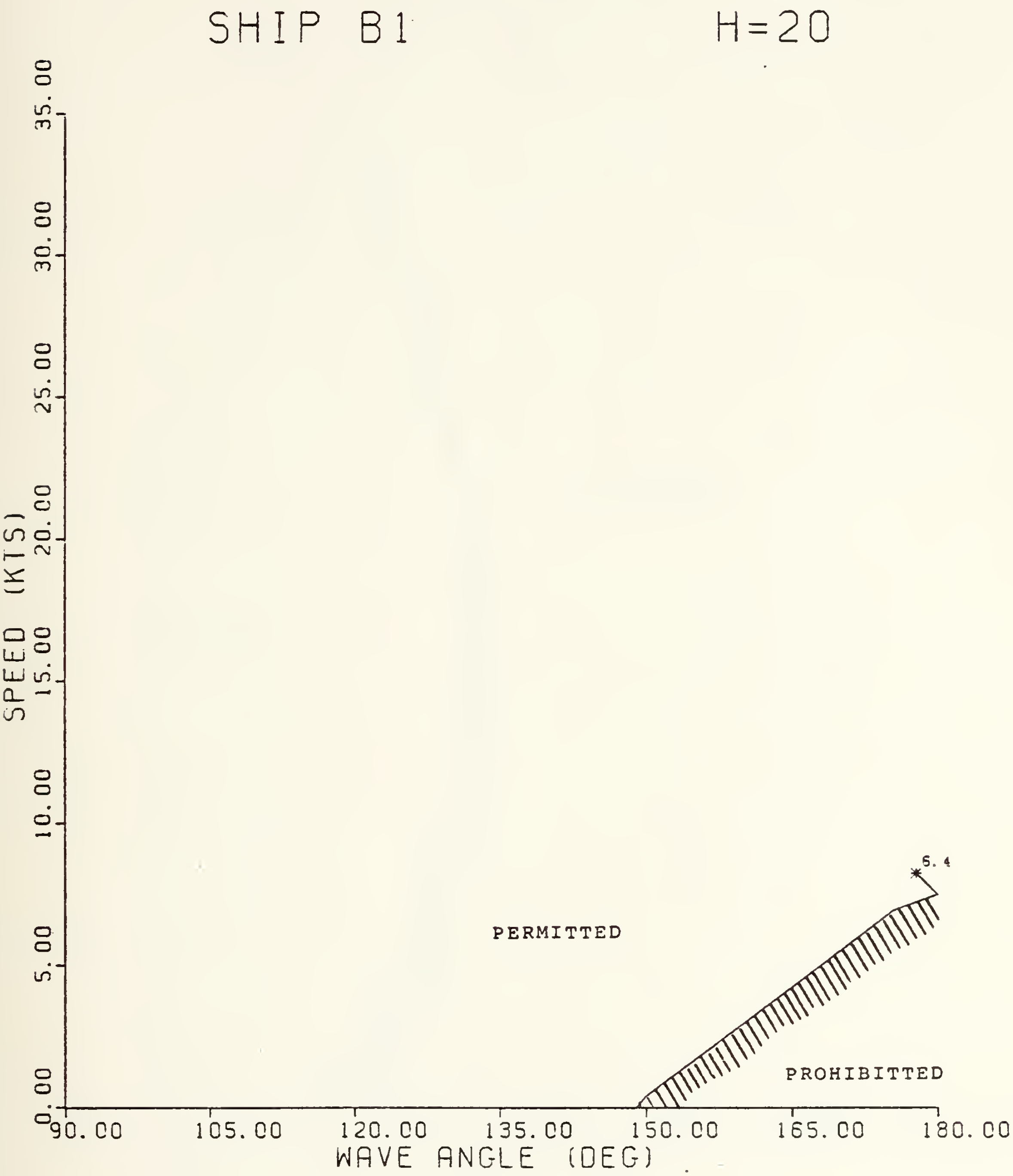
BØW ACCELERATIØN (FT/SEC2)
SHIP B1
H=25
MAX = 8.279
3.C
4.C
5.C
6.C
7.C
8.C
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

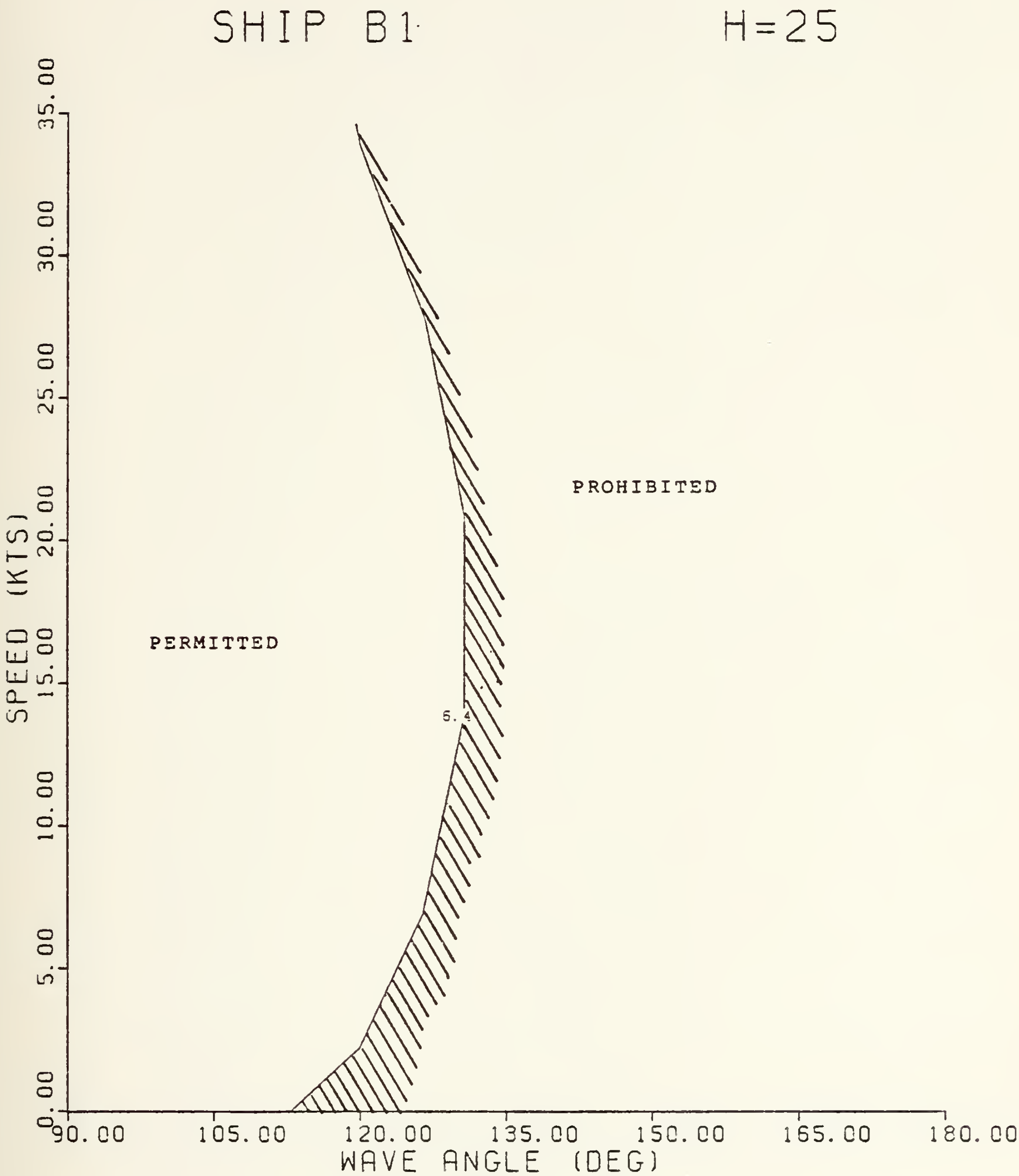
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

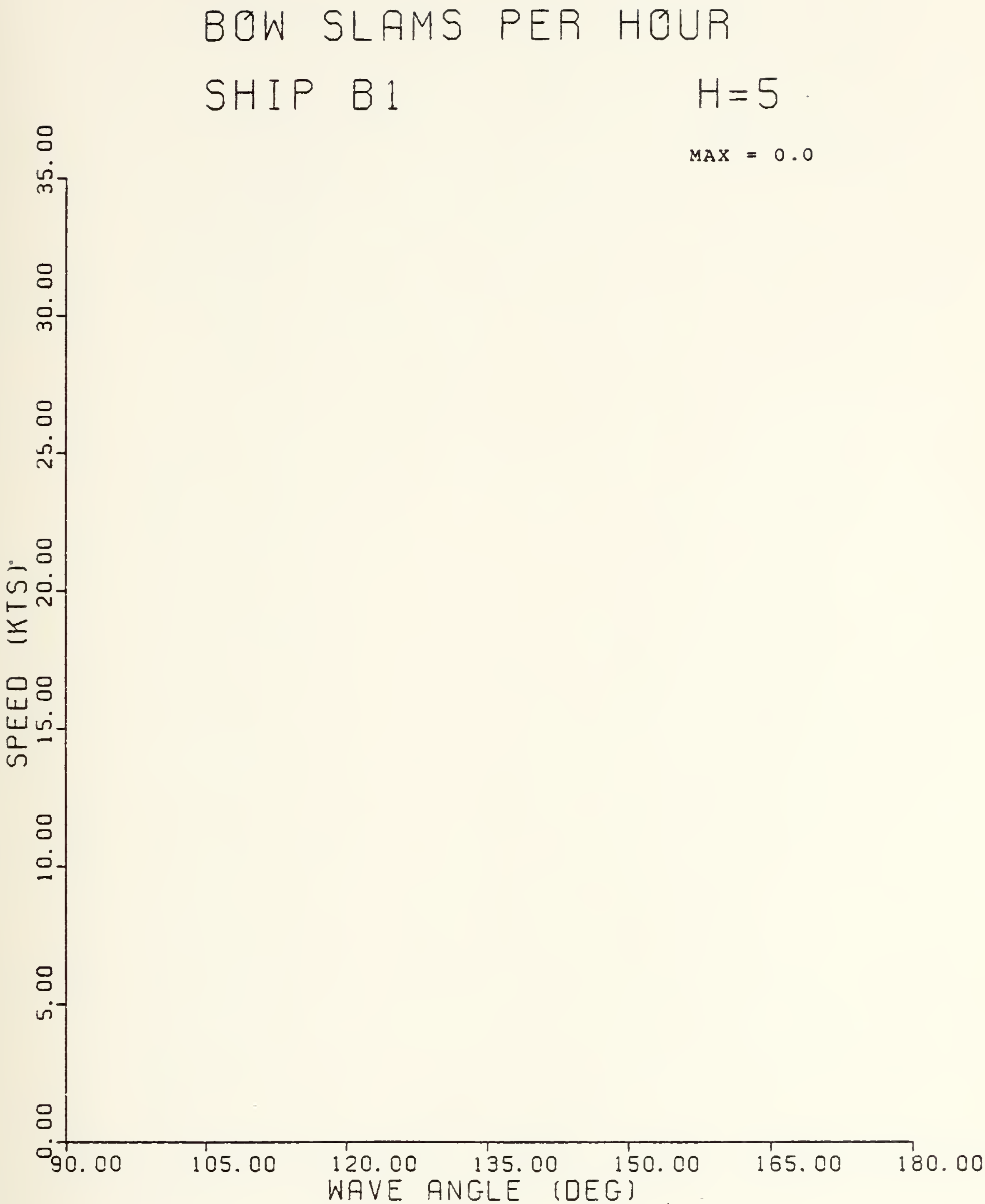
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2



OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

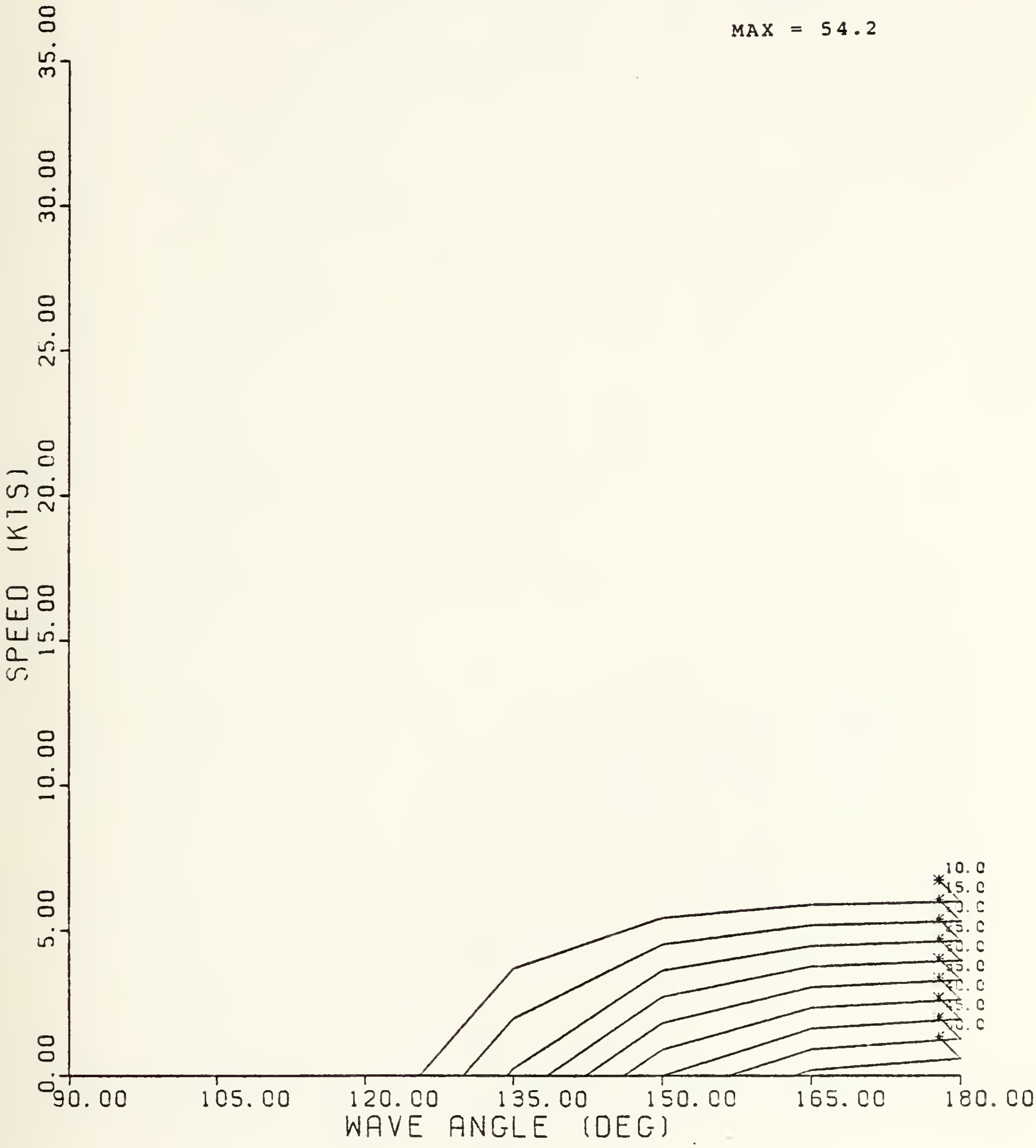


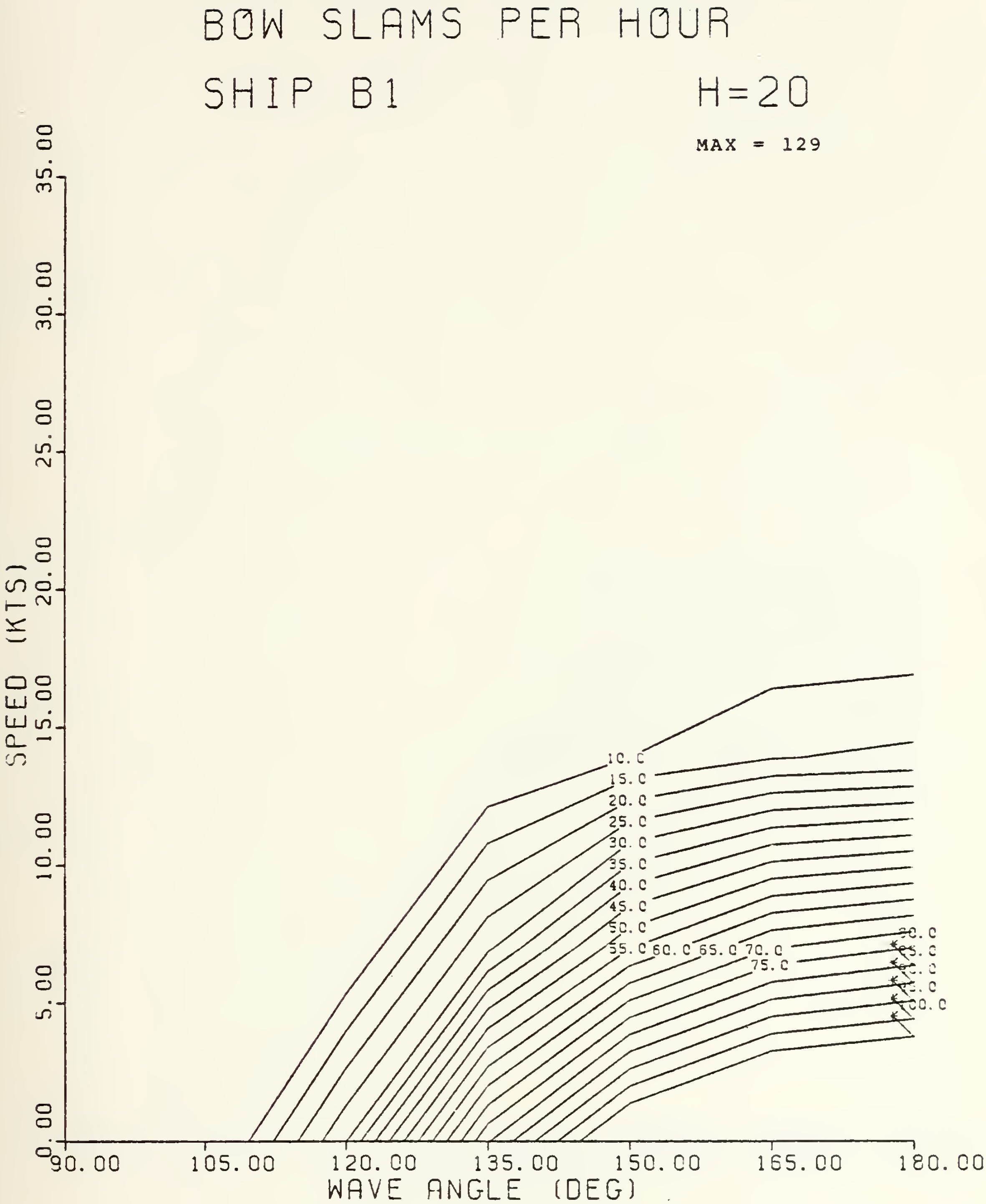

BØW SLAMS PER HØUR
SHIP B1
H=5
MAX = 0.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

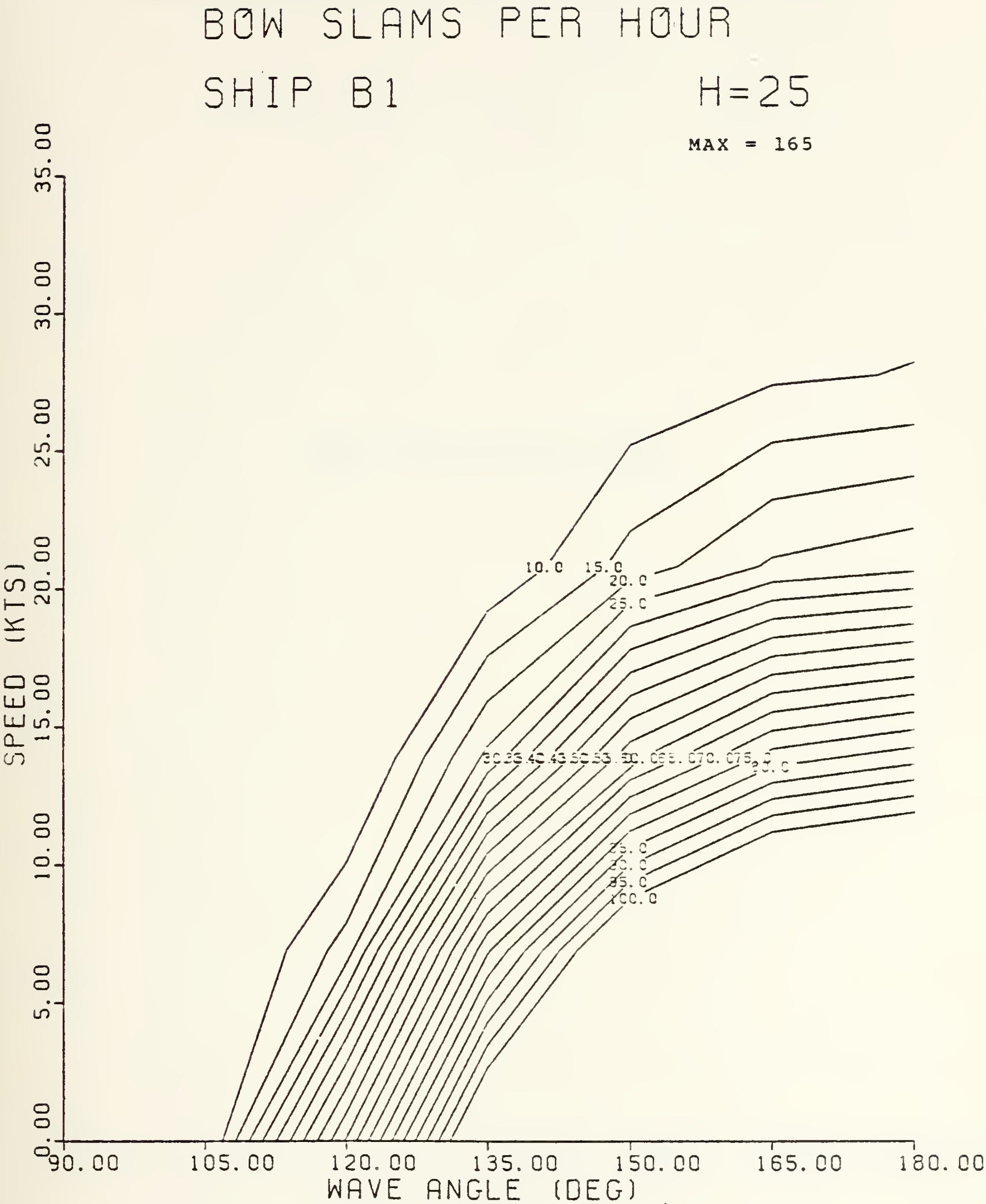

BØW SLAMS PER HØUR
SHIP B1
H=10
MAX = 0.014
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

BØW SLAMS PER HOUR

SHIP B1 H=15




BOW SLAMS PER HOUR
SHIP B1
H=20
MAX = 129
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0

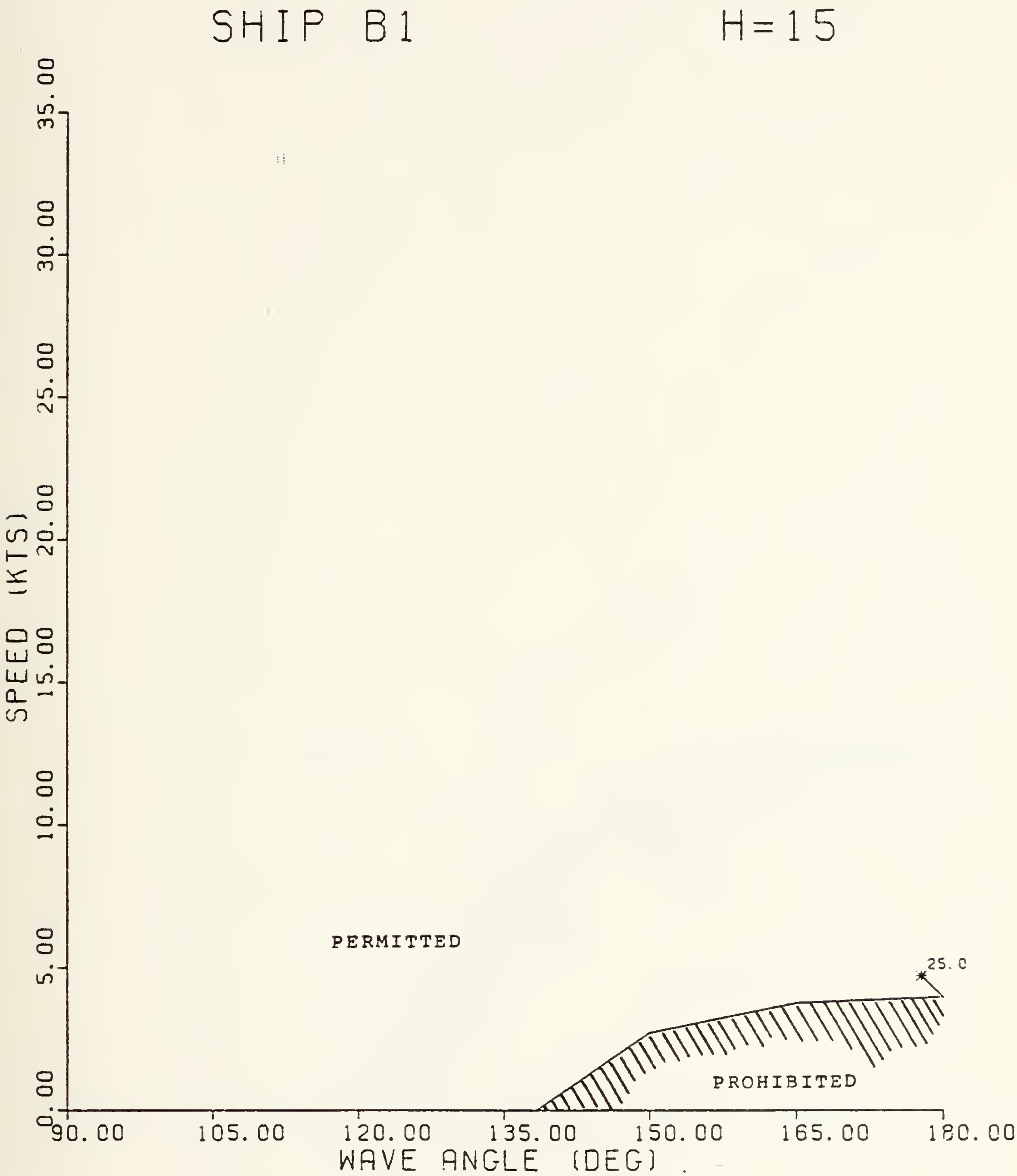


BOW SLAMS PER HOUR
SHIP B1
H=25
MAX = 165
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
20.0
25.0
100.0

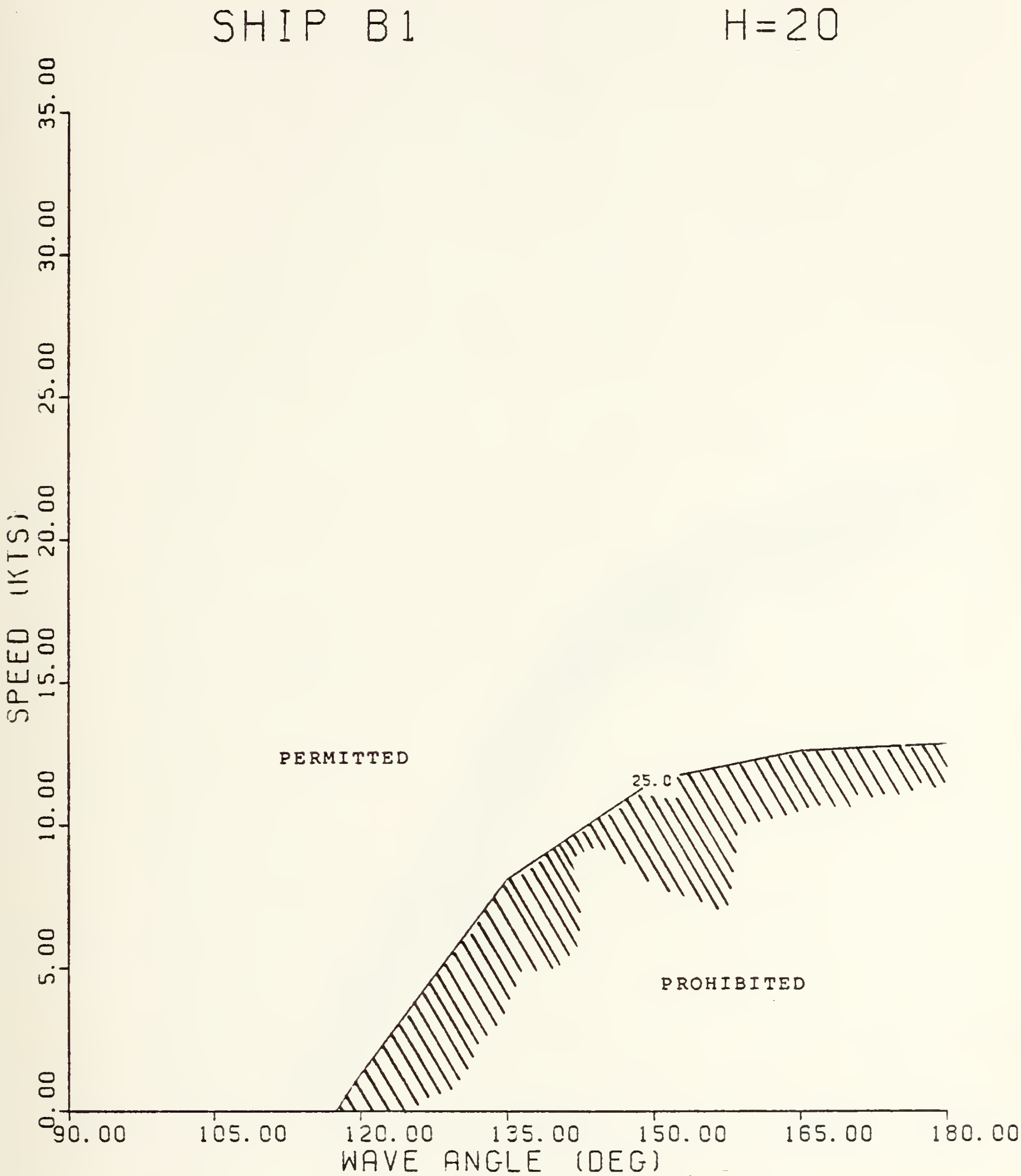
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

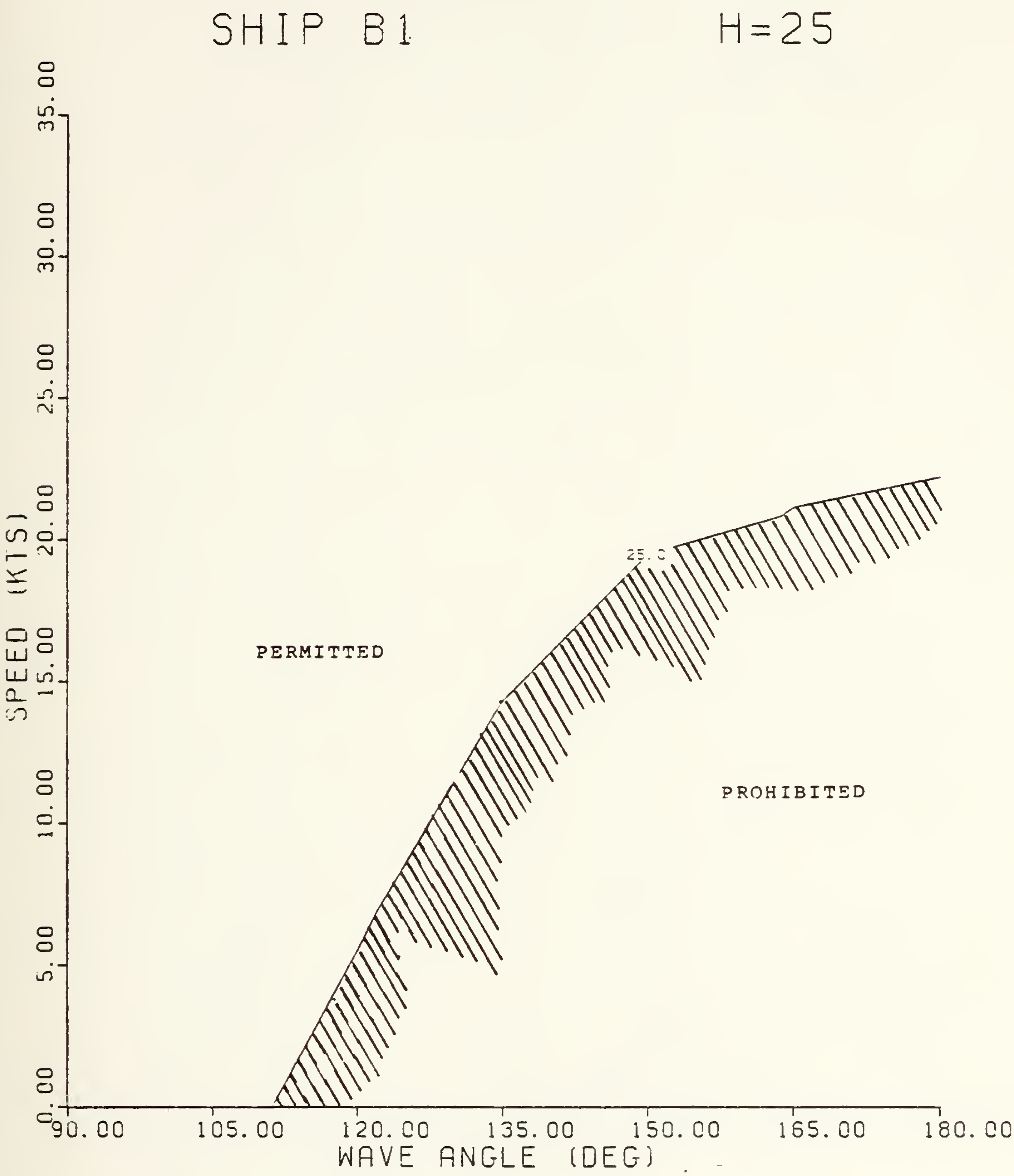
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

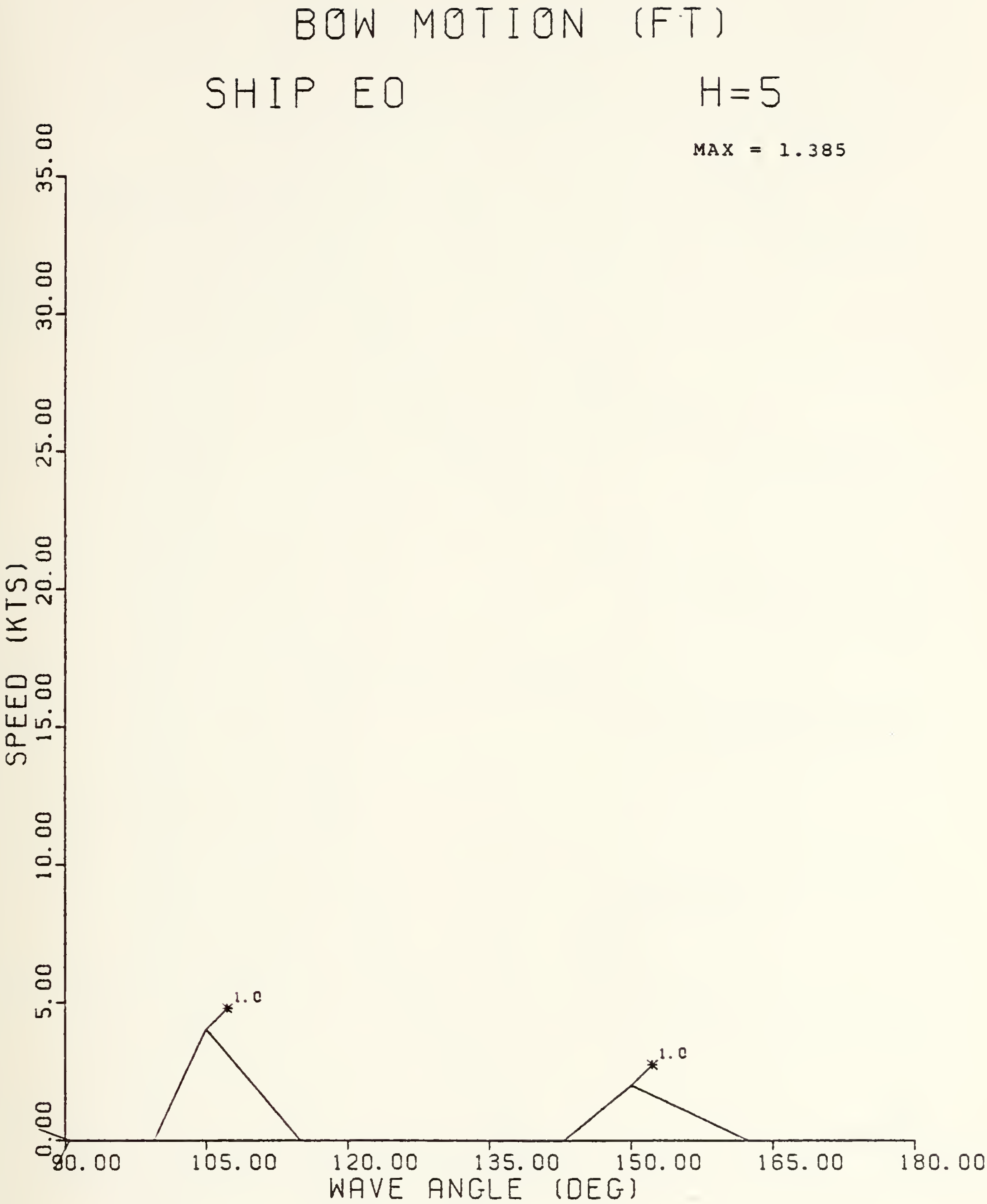


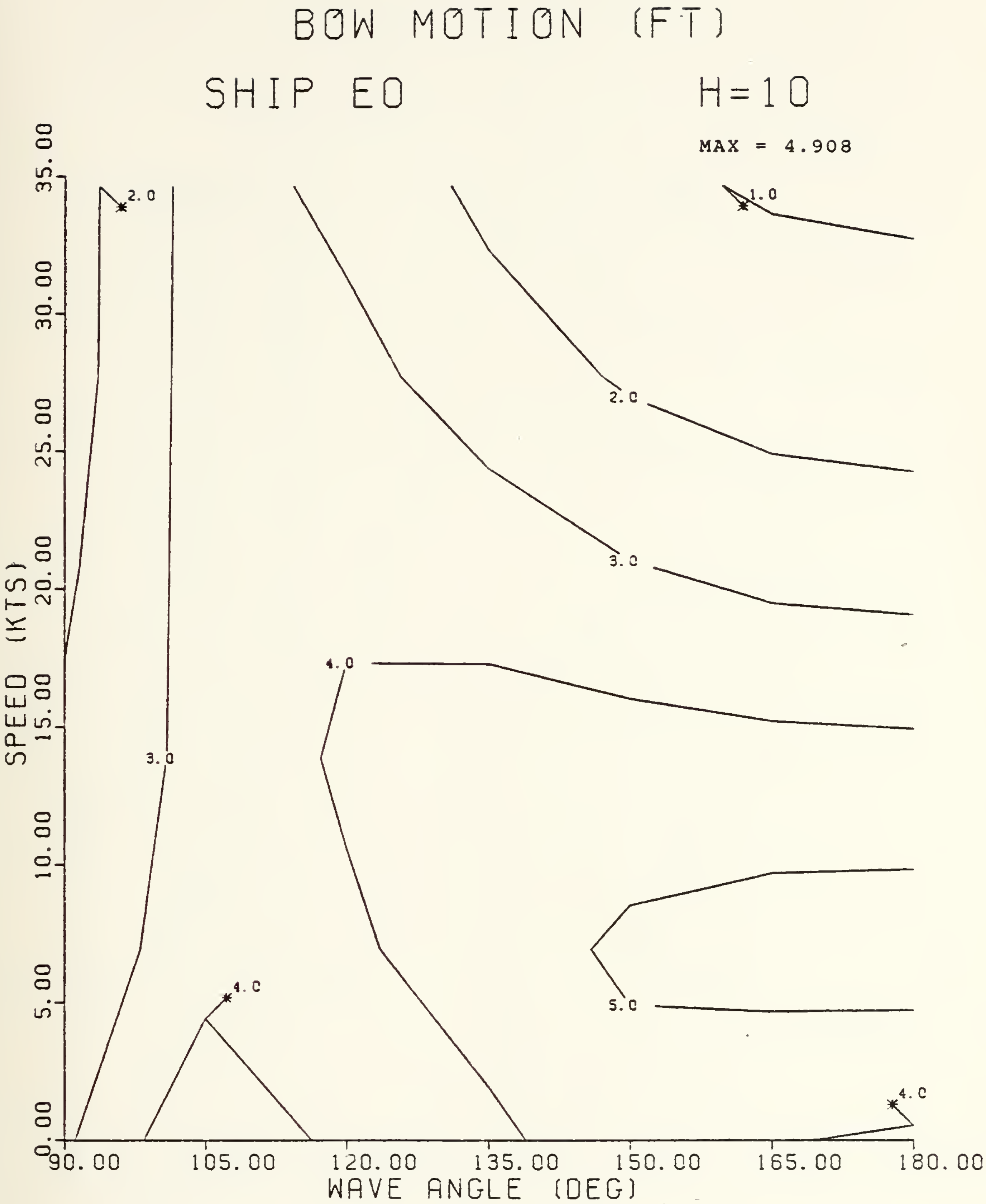
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

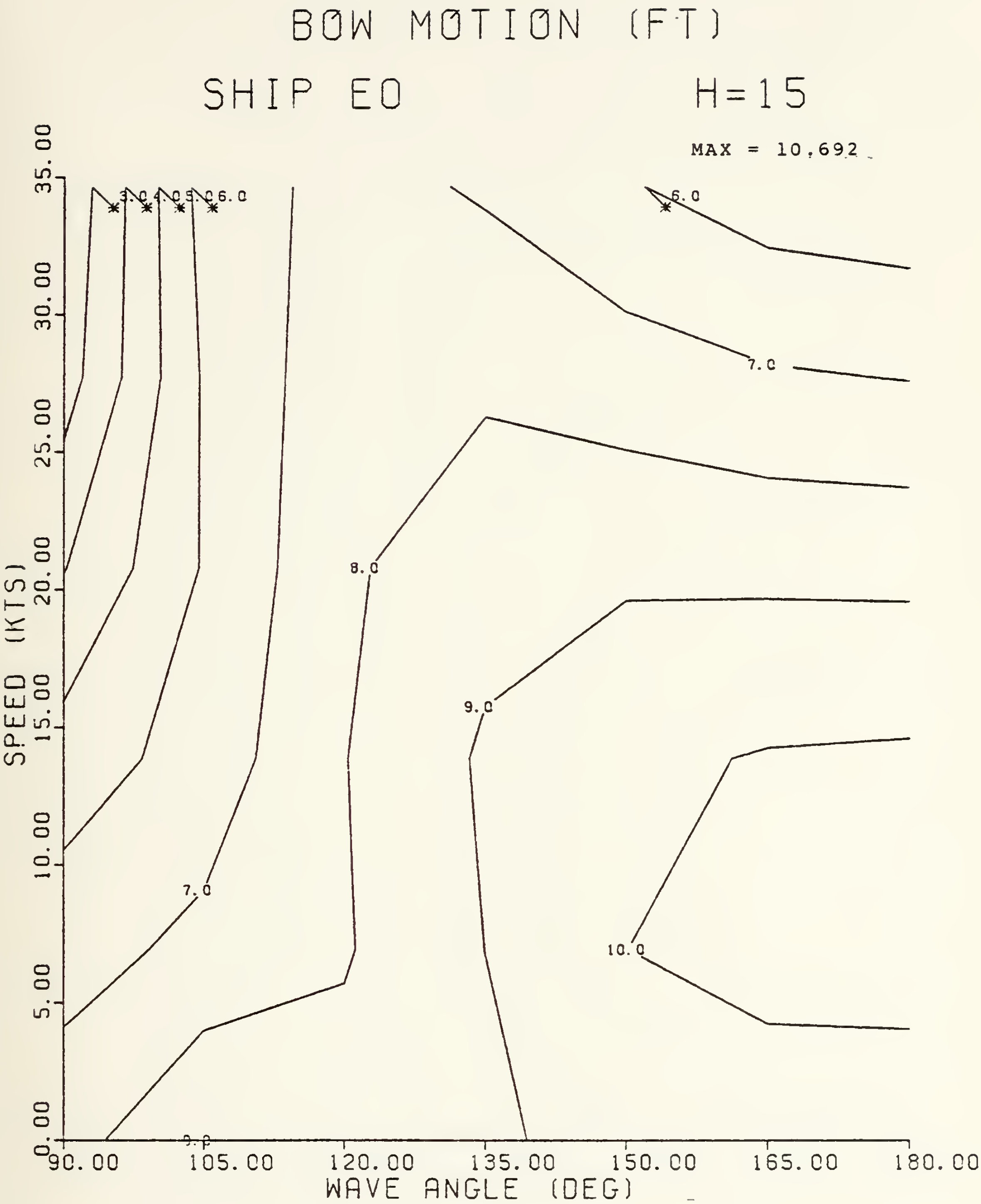


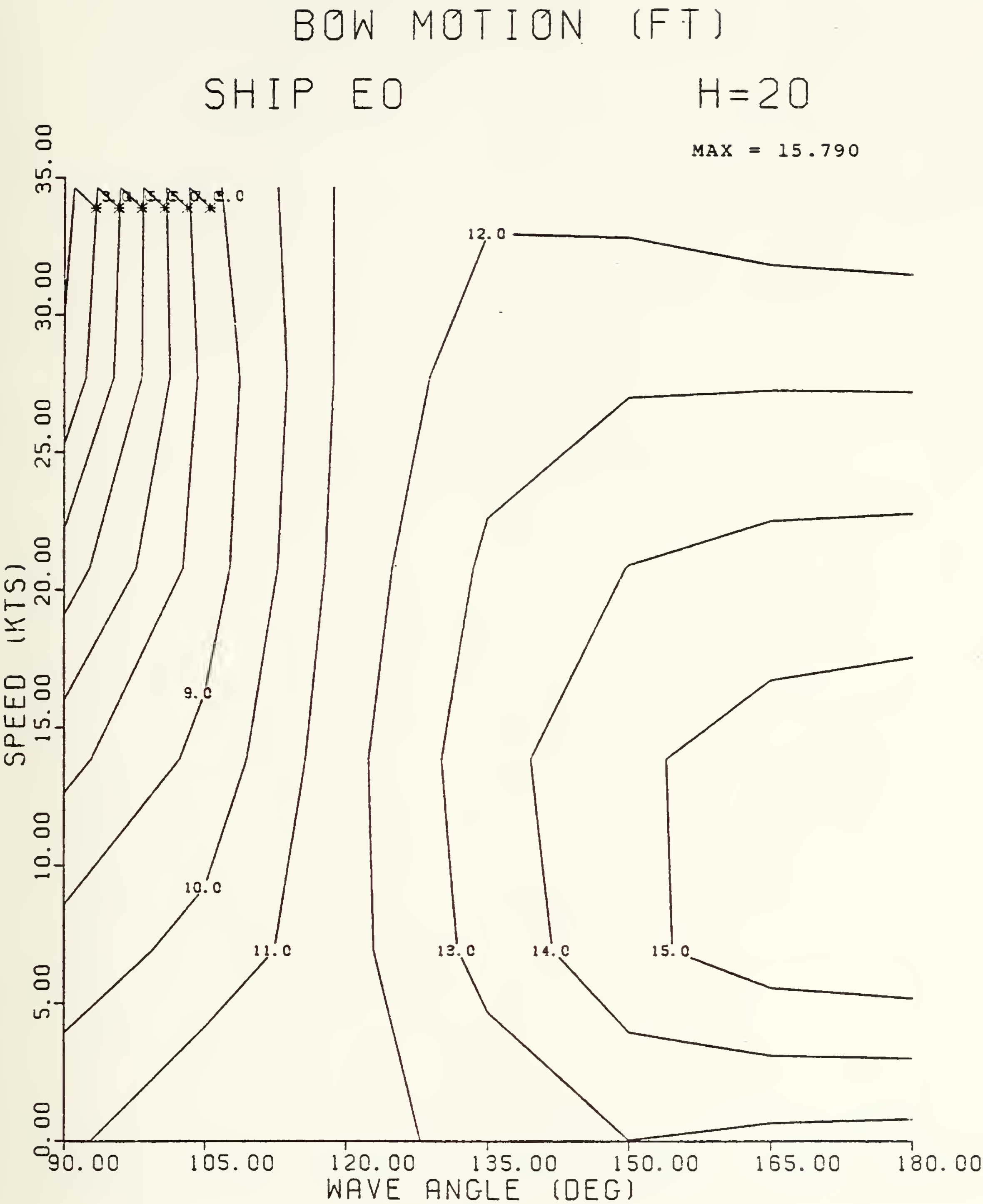
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR



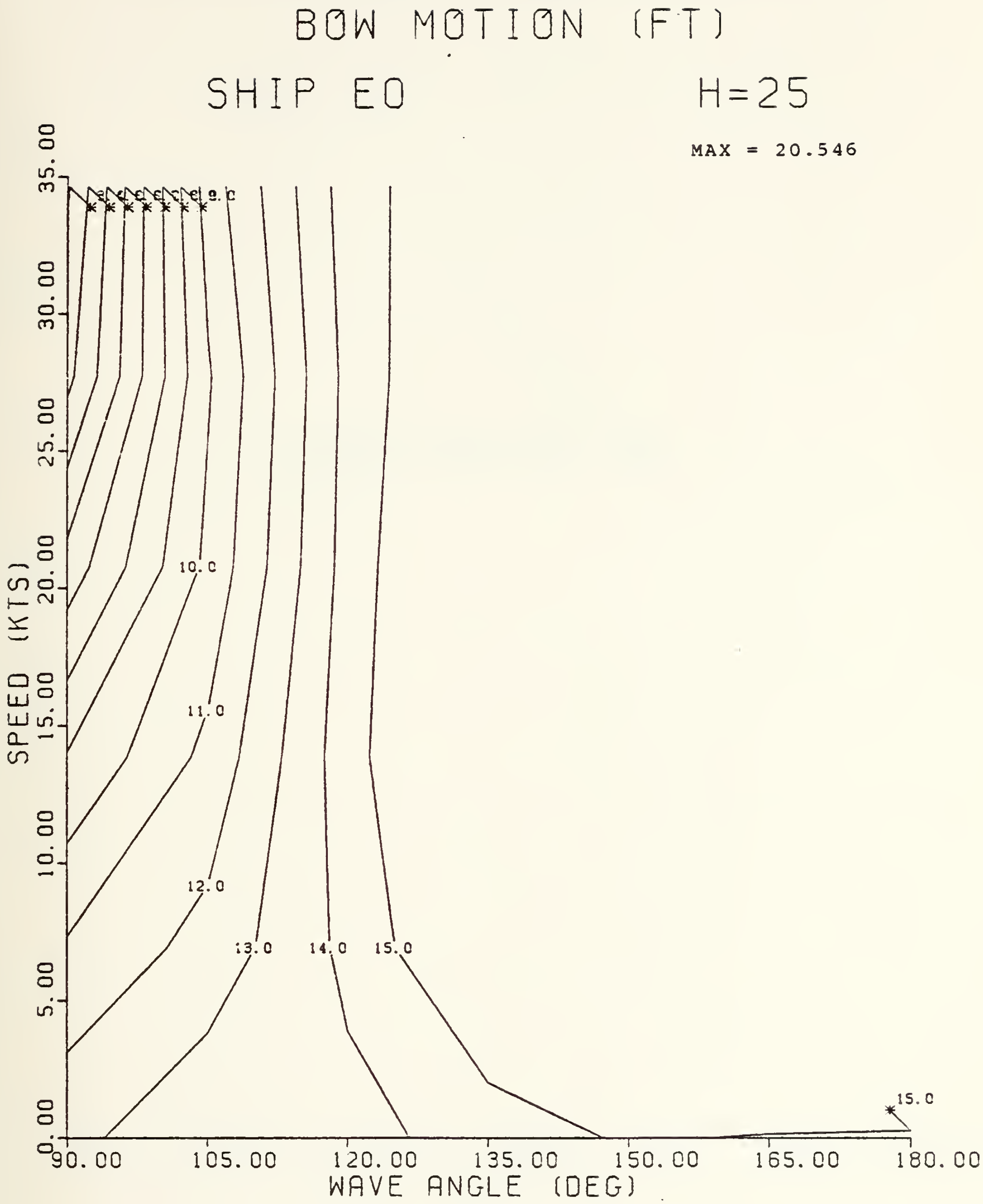

BOW MOTION (FT)
SHIP EO
H=5
MAX = 1.385
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1.0
1.0
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW MOTION (FT)
SHIP EO
H=10
MAX = 4.908
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
WAVE ANGLE (DEG)
90.00
105.00
120.00
135.00
150.00
165.00
180.00
1.0
2.0
2.0
3.0
3.0
4.0
4.0
4.0
5.0


BOW MOTION (FT)
SHIP EO
H=15
MAX = 10.692
3.0
4.0
5.0
6.0
6.0
7.0
8.0
7.0
9.0
10.0
9.0
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
SPEED (KTS)
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

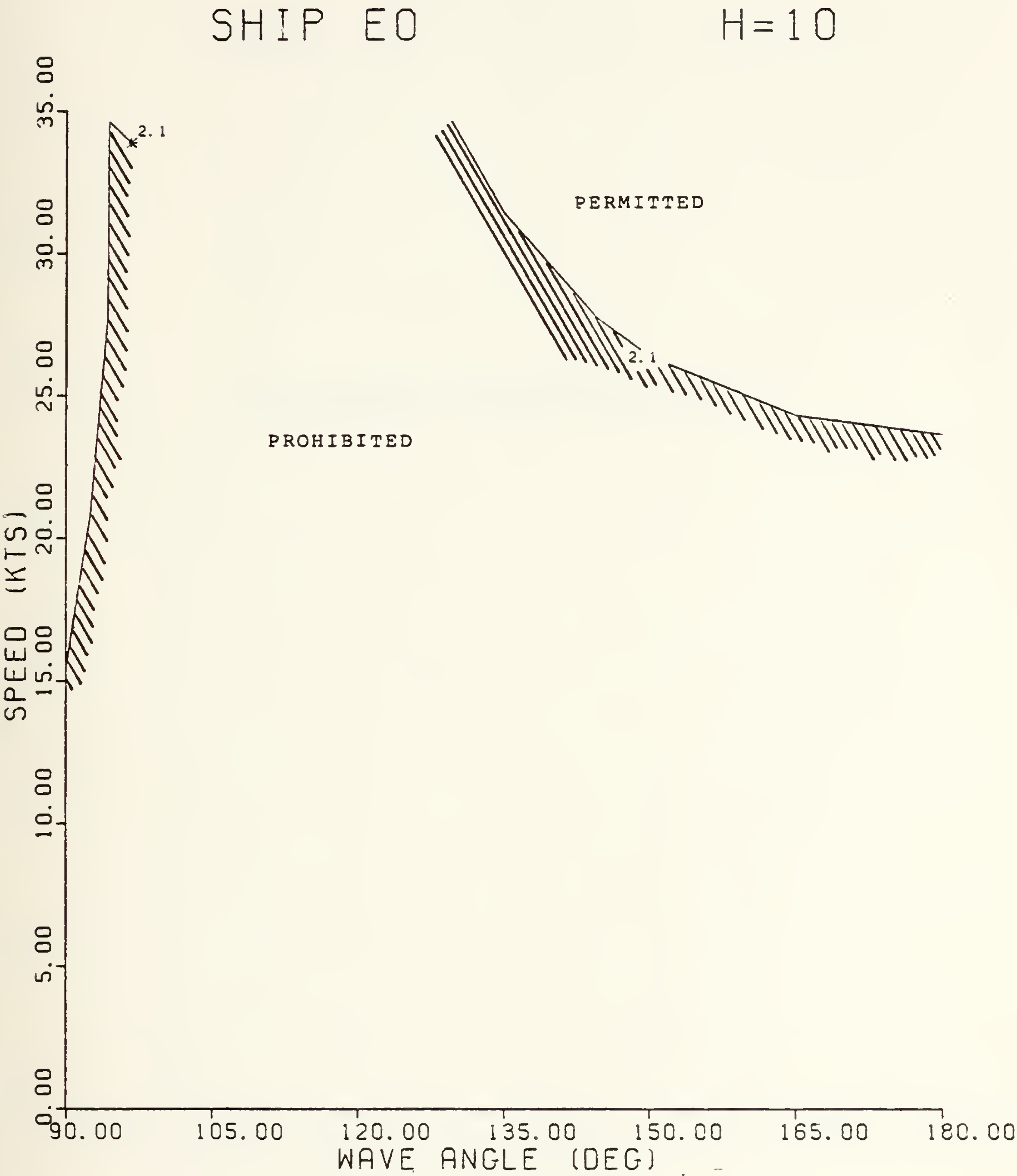


BOW MOTION (FT)
SHIP EO
H=20
MAX = 15.790
12.0
9.0
10.0
11.0
13.0
14.0
15.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW MOTION (FT)
SHIP EO
H=25
MAX = 20.546
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
10.0
11.0
12.0
13.0
14.0
15.0
15.0
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

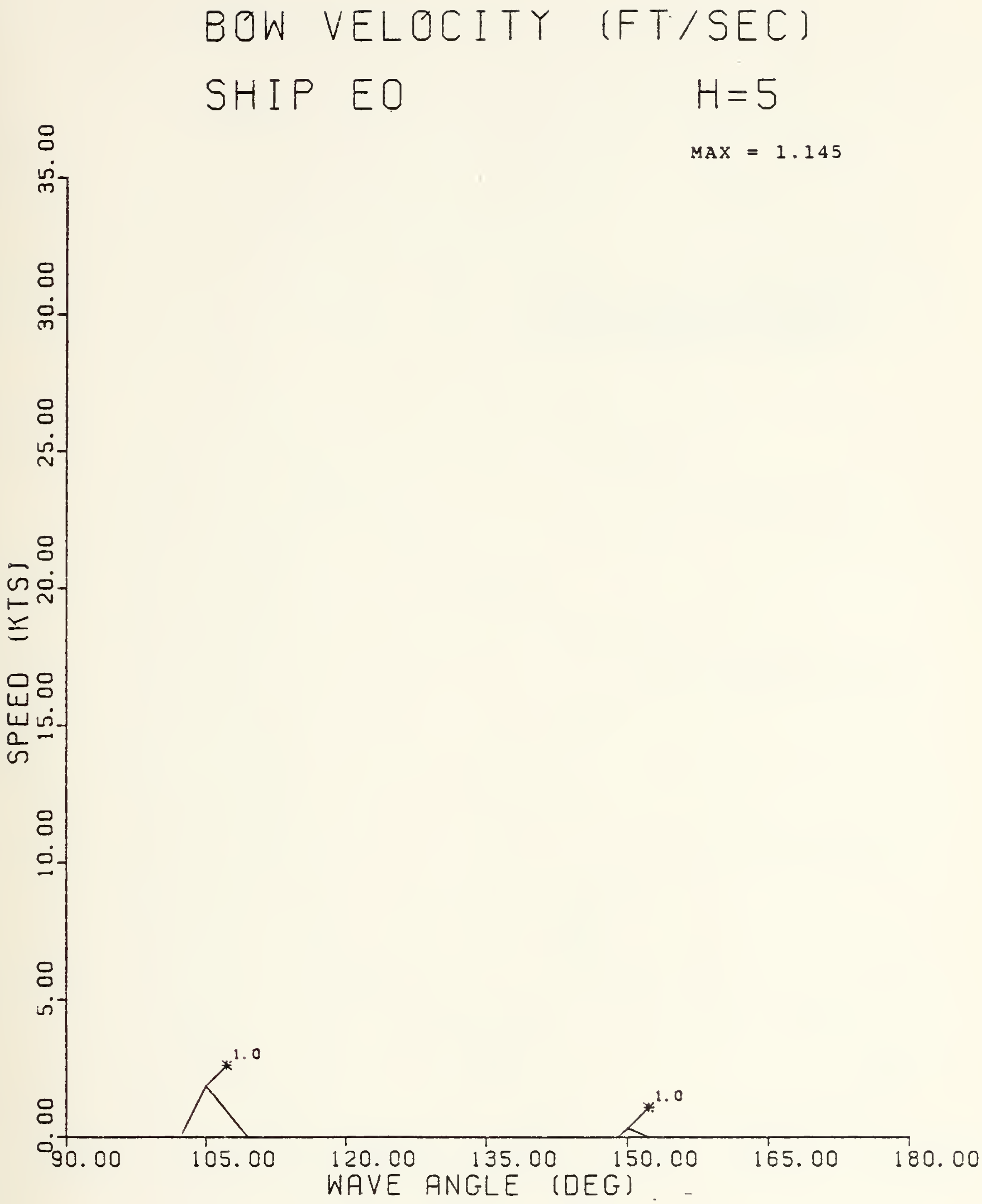
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

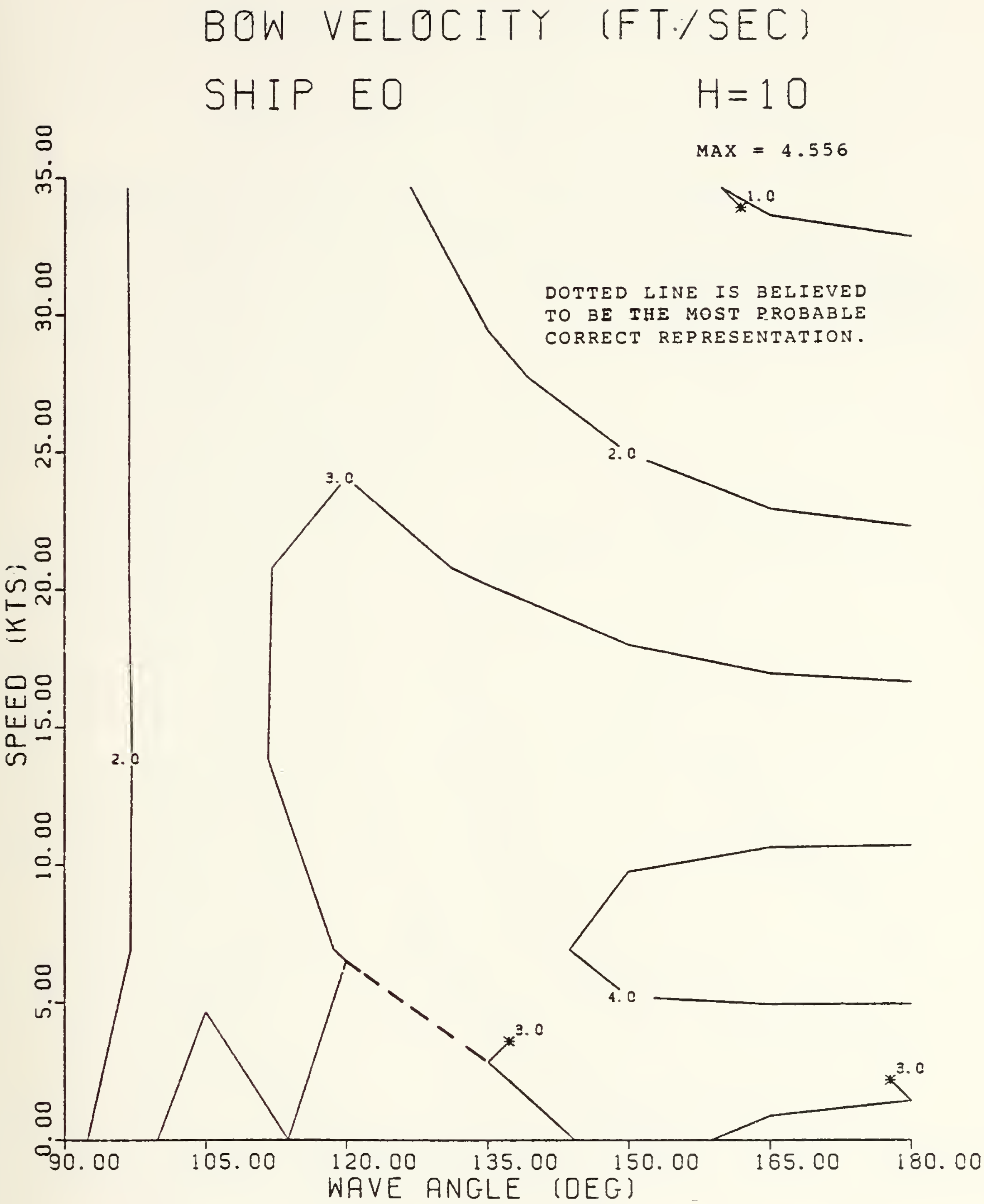


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

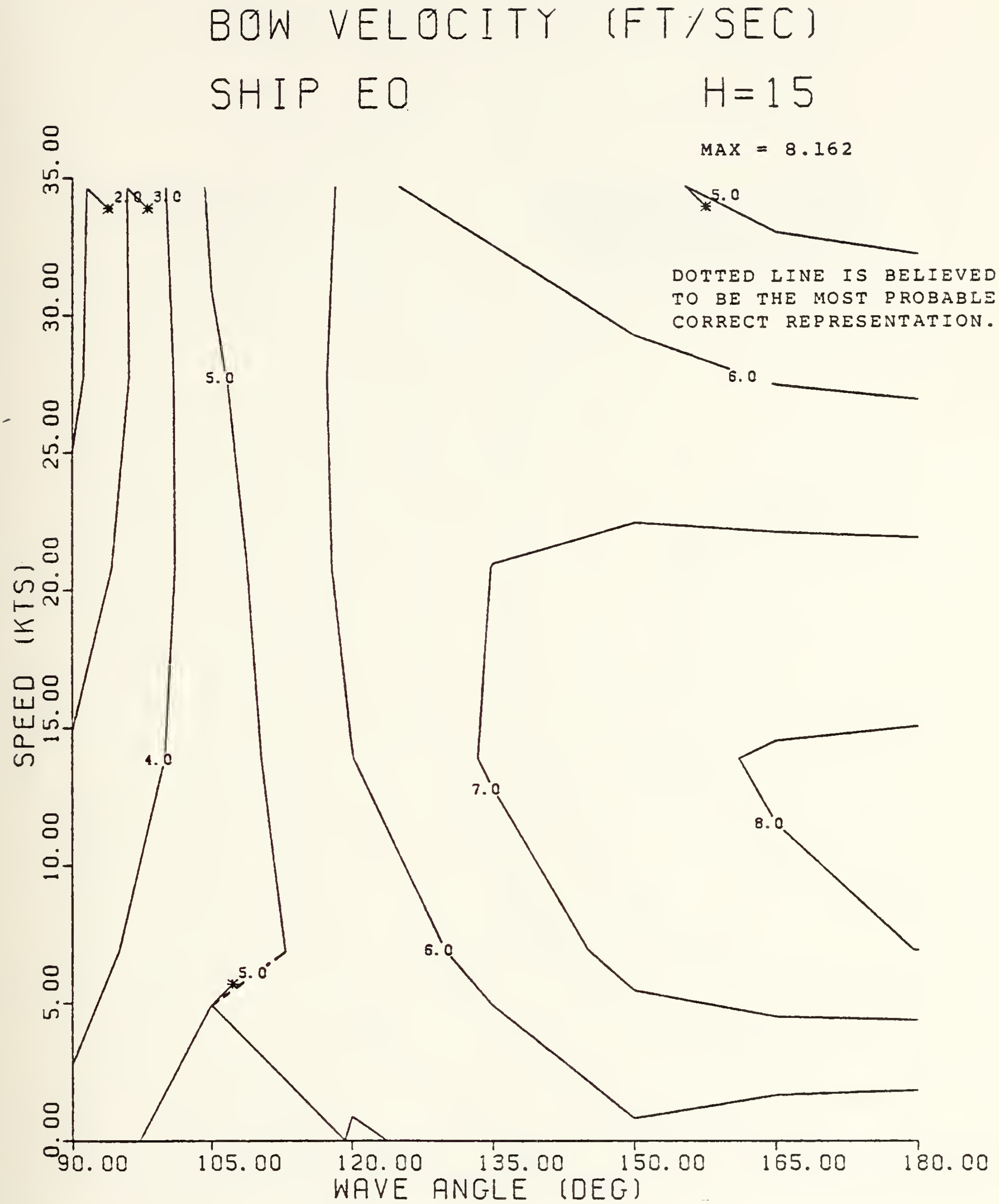
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

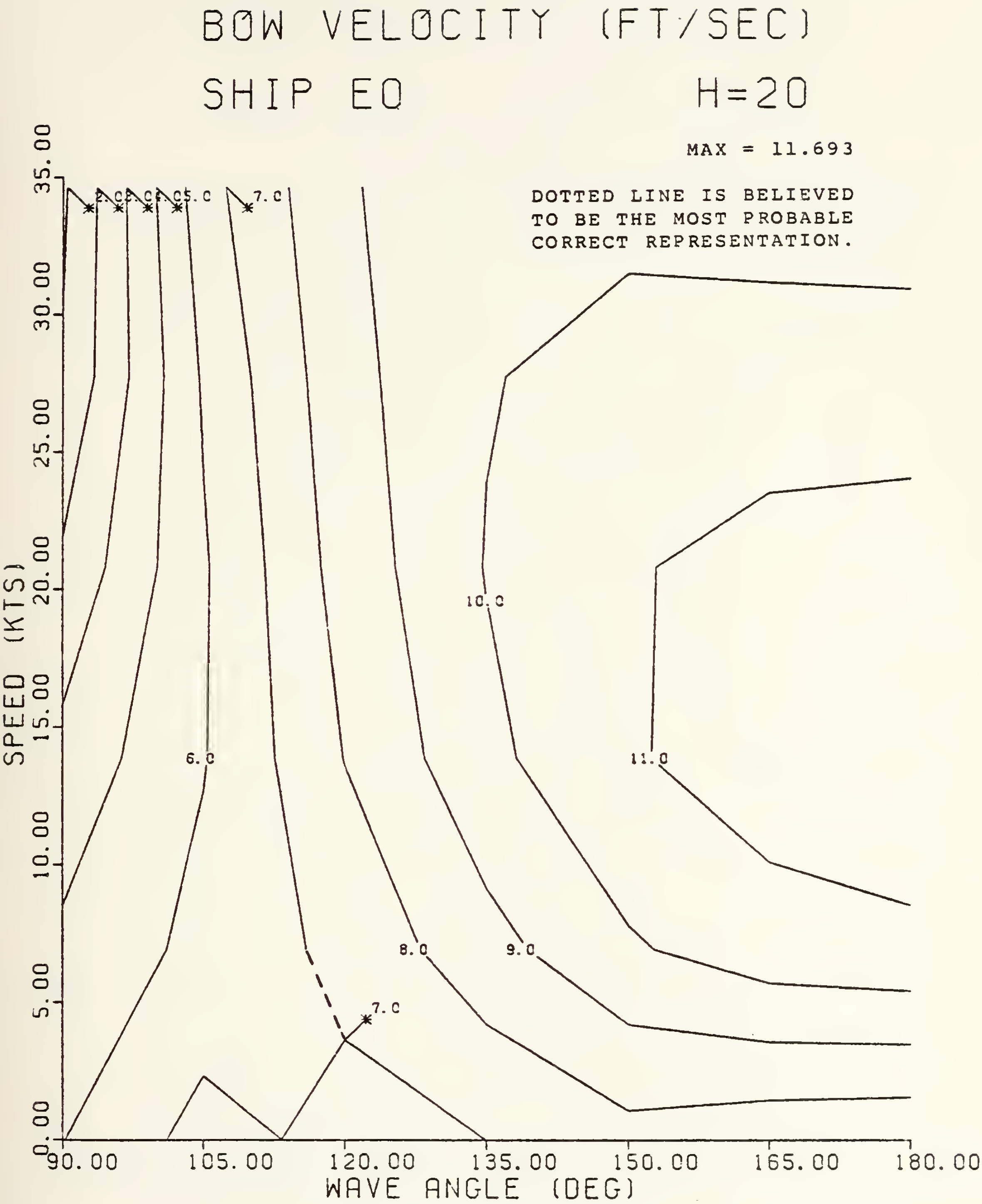
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET


BØW VELOCITY (FT/SEC)
SHIP EO H=5
MAX = 1.145
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
1.0
1.0



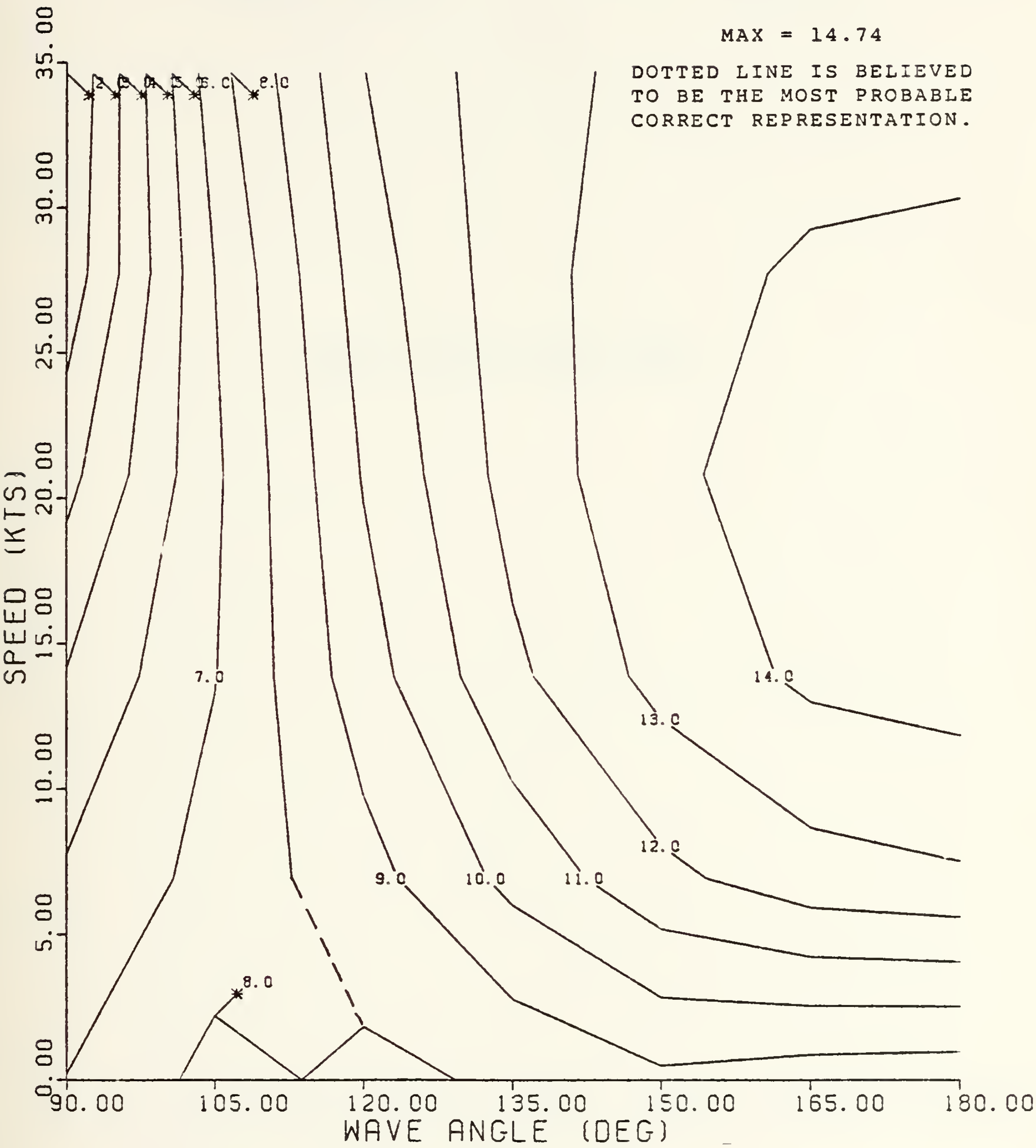
BOW VELOCITY (FT/SEC)
SHIP EO H=10
MAX = 4.556
DOTTED LINE IS BELIEVED TO BE THE MOST PROBABLE CORRECT REPRESENTATION.
1.0
2.0
3.0
2.0
4.0
3.0
3.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW VELOCITY (FT/SEC)
SHIP EO H=15
MAX = 8.162
DOTTED LINE IS BELIEVED TO BE THE MOST PROBABLE CORRECT REPRESENTATION.
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
WAVE ANGLE (DEG)
90.00
105.00
120.00
135.00
150.00
165.00
180.00
2.0
3.0
4.0
5.0
6.0
7.0
8.0


BOW VELOCITY (FT/SEC)
SHIP EQ
H=20
MAX = 11.693
DOTTED LINE IS BELIEVED
TO BE THE MOST PROBABLE
CORRECT REPRESENTATION.
7.0
6.0
8.0
9.0
10.0
11.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
WAVE ANGLE (DEG)
90.00
105.00
120.00
135.00
150.00
165.00
180.00

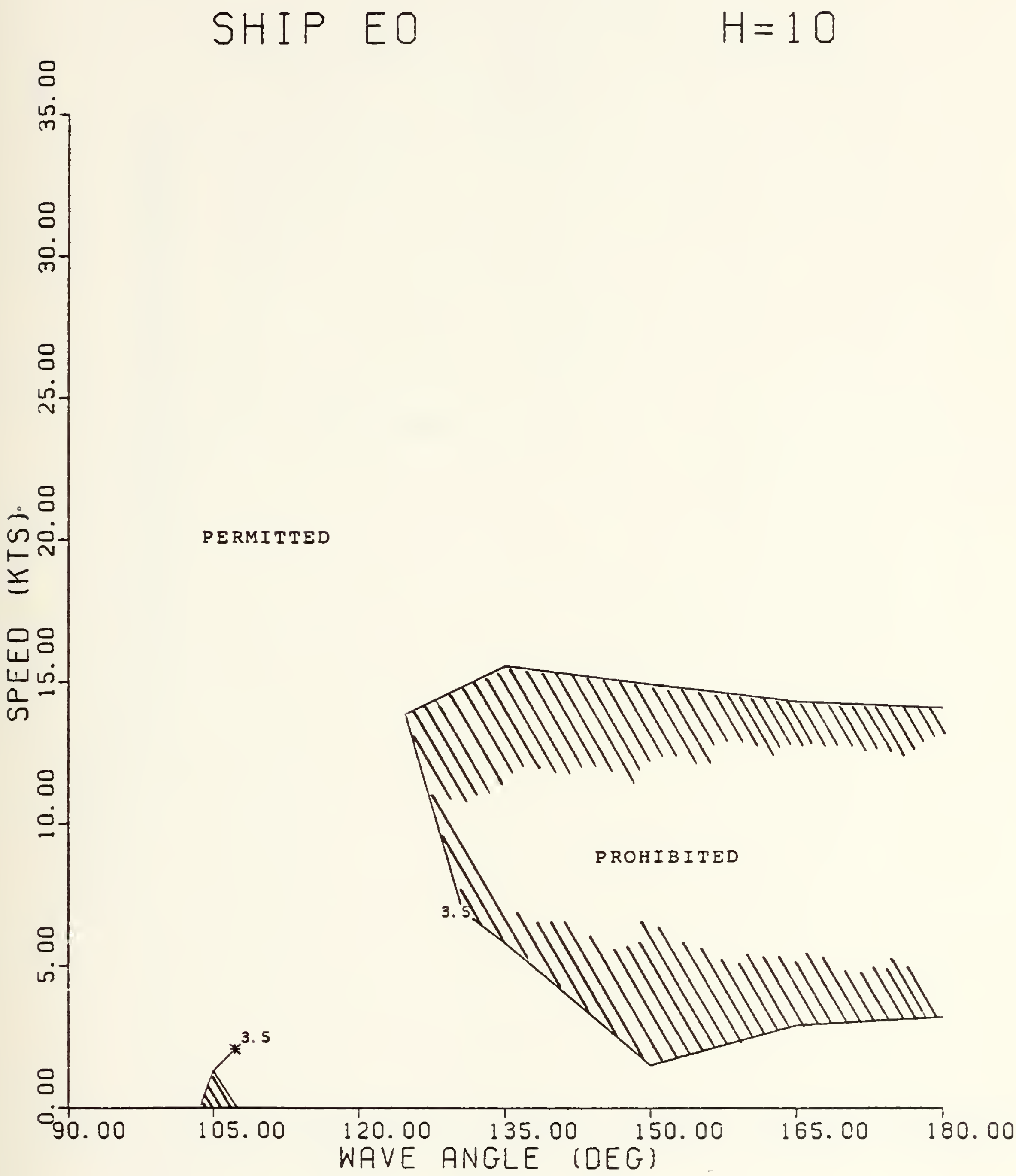
BØW VELØCITY (FT/SEC)

SHIP EQ H=25



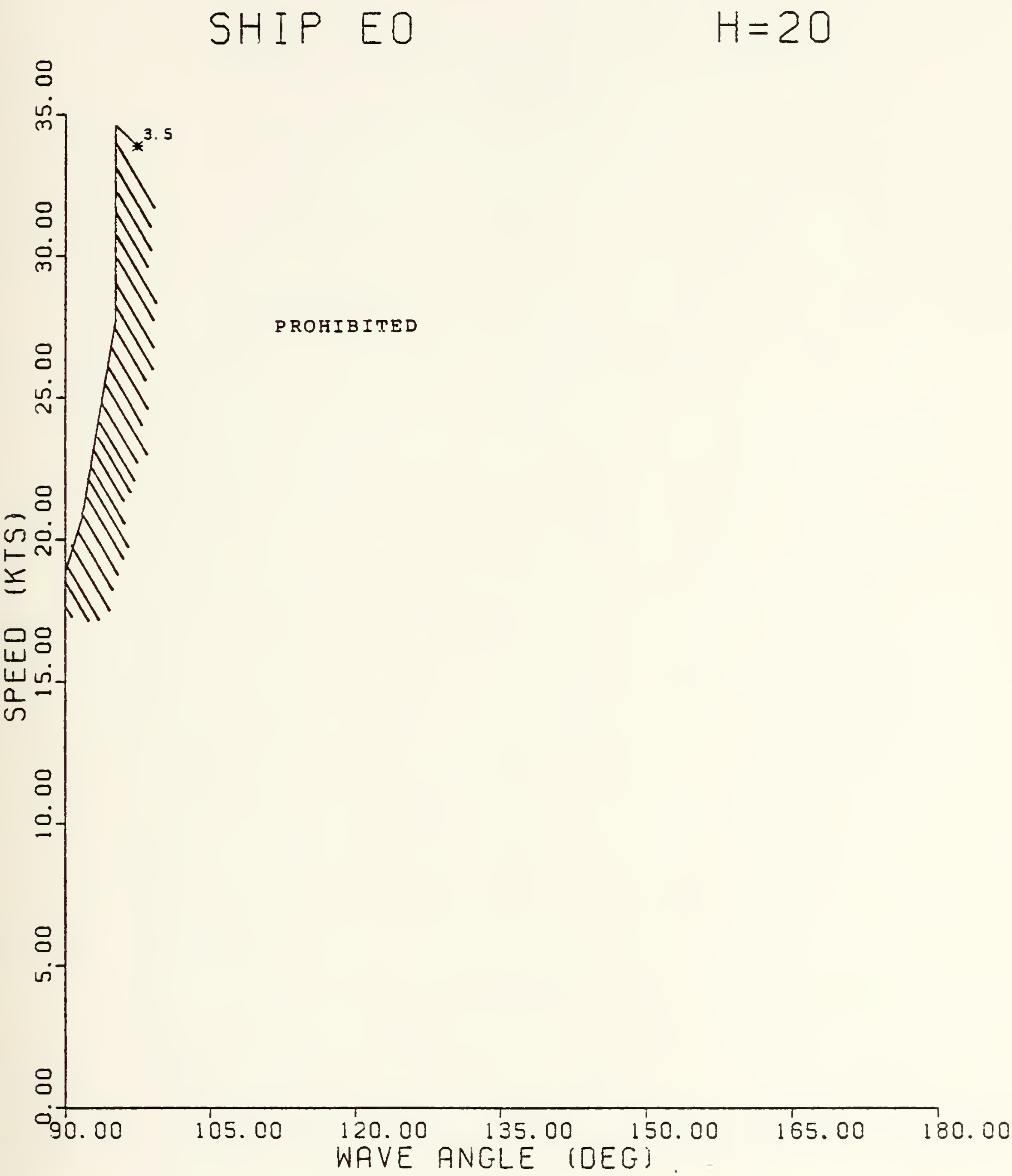
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

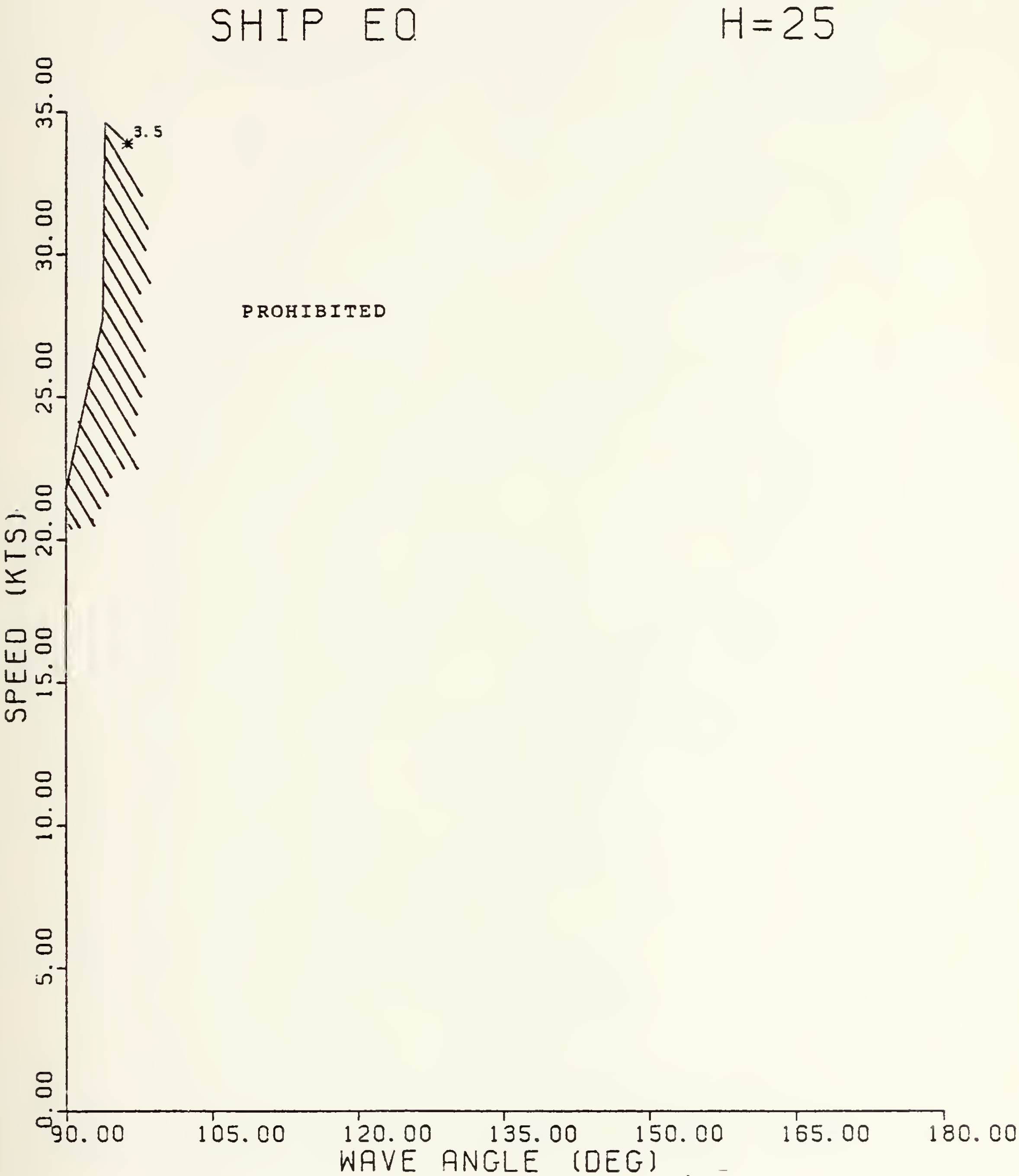


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

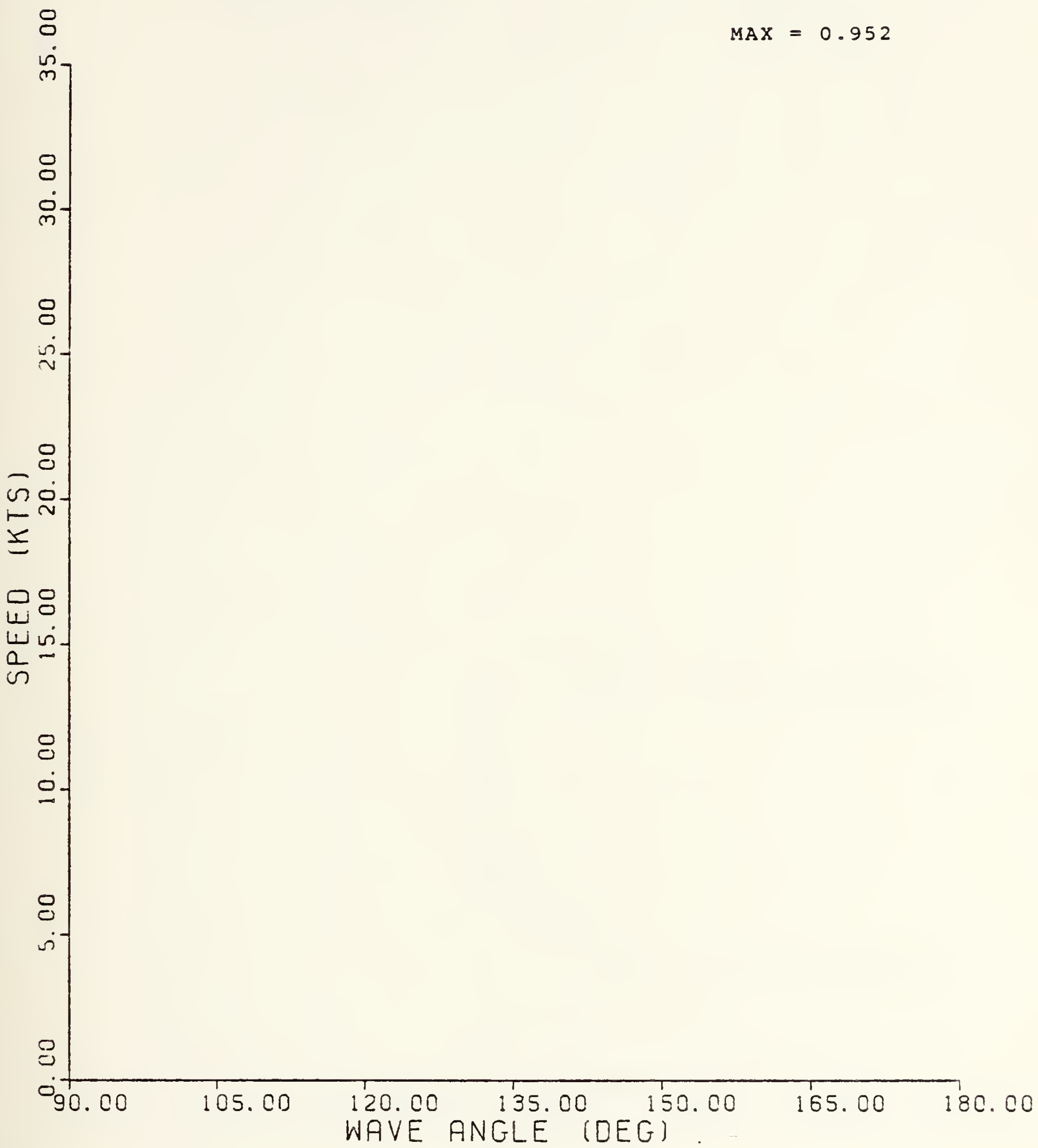


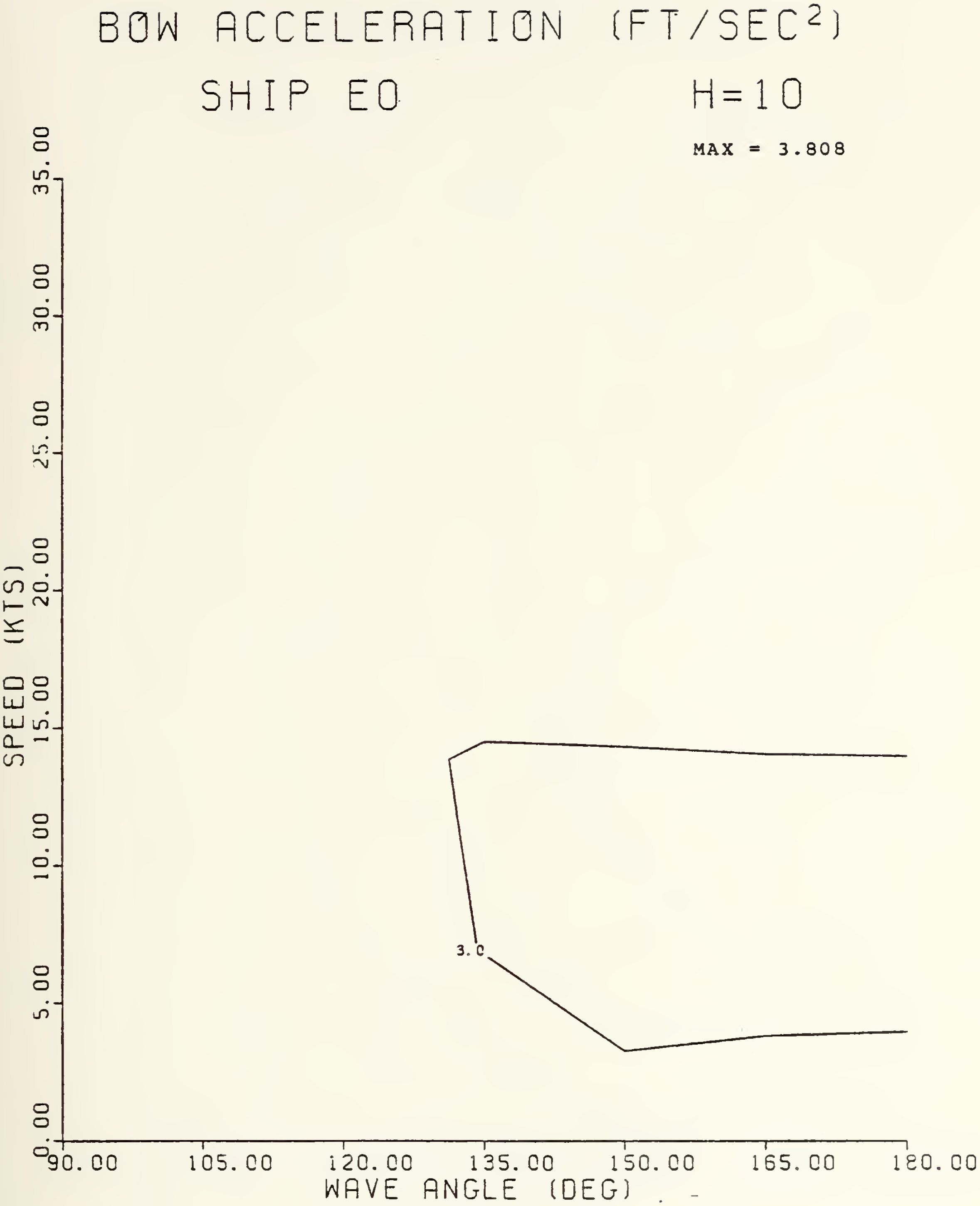
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

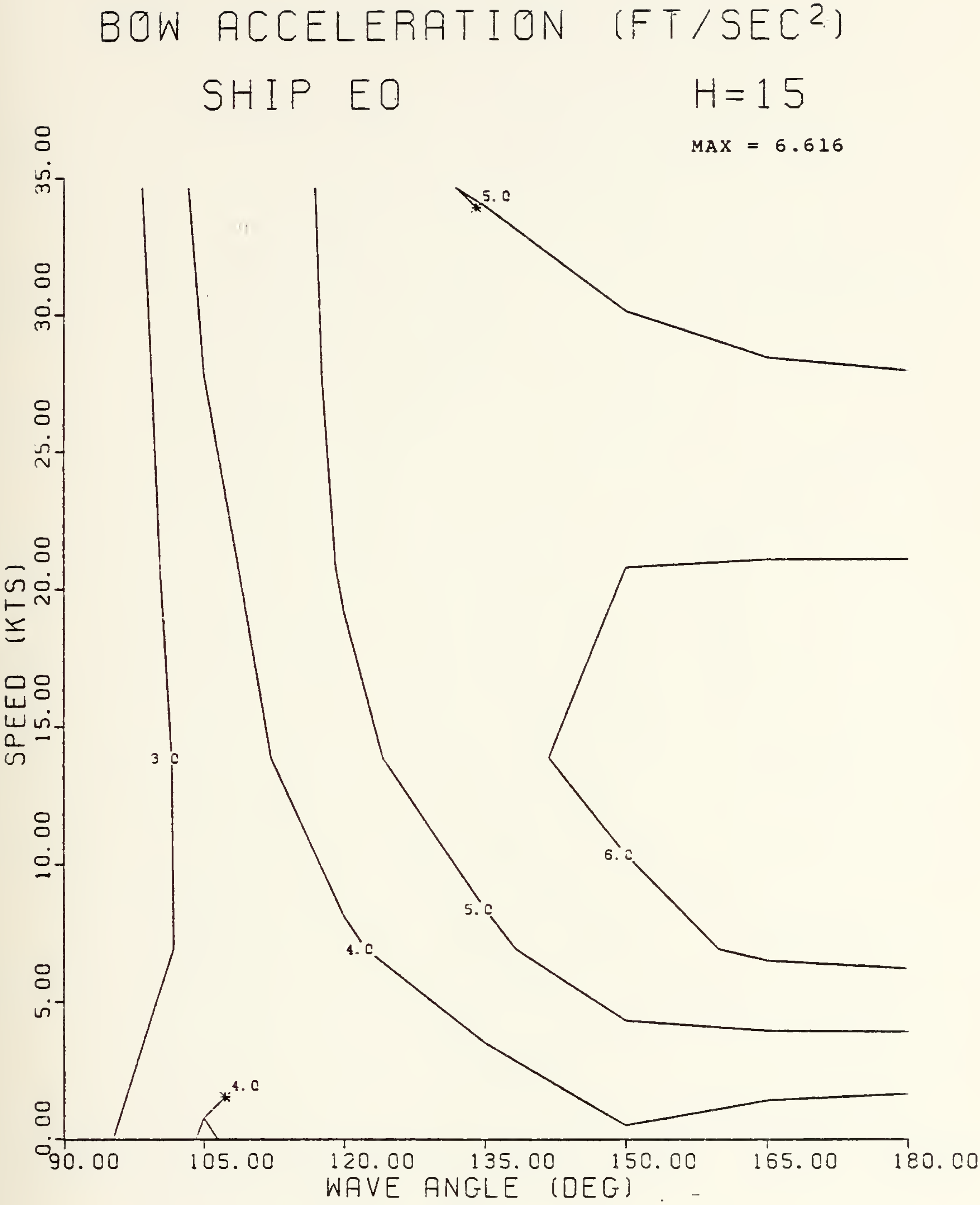


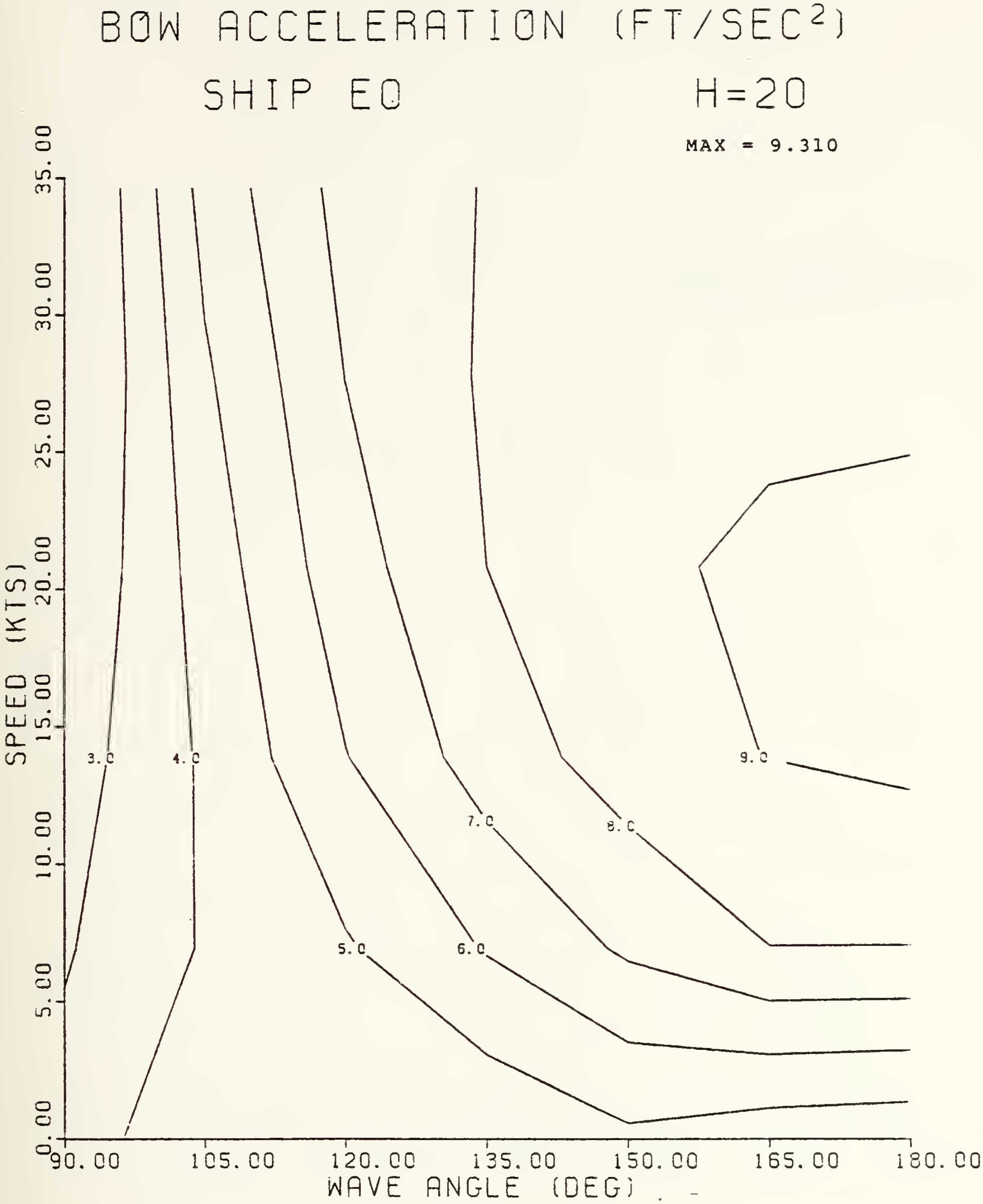
BØW ACCELERATIØN (FT/SEC^2)

SHIP EO H=5

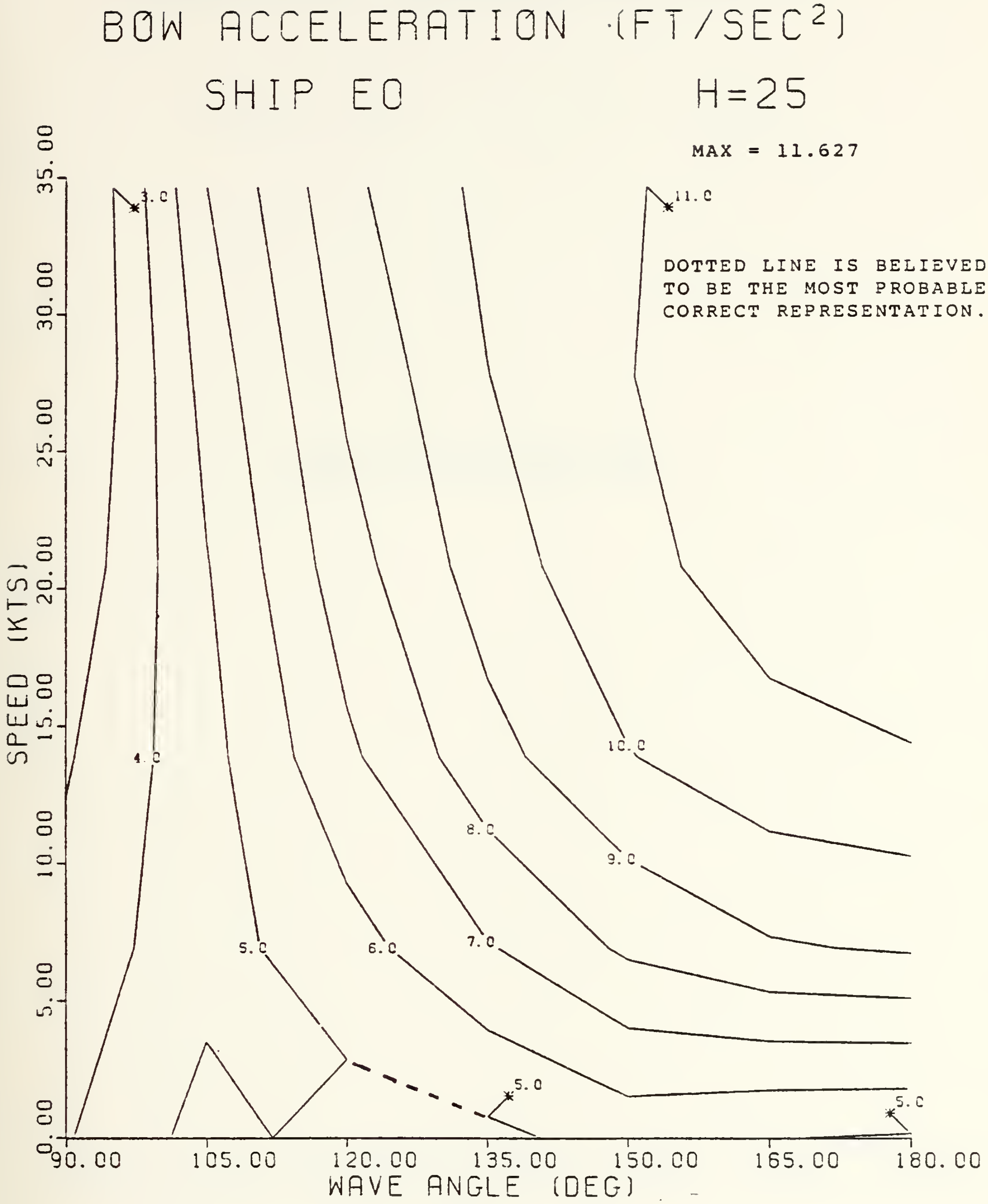



BØW ACCELERATIØN (FT/SEC²)
SHIP EO
H=10
MAX = 3.808
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
SPEED (KTS)
3.0
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BØW ACCELERATIØN (FT/SEC2)
SHIP EO
H=15
MAX = 6.616
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
3.0
4.0
5.0
6.0
4.0
5.0



BOW ACCELERATION (FT/SEC2)
SHIP EO
H=20
MAX = 9.310
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
3.0
4.0
5.0
6.0
7.0
8.0
9.0

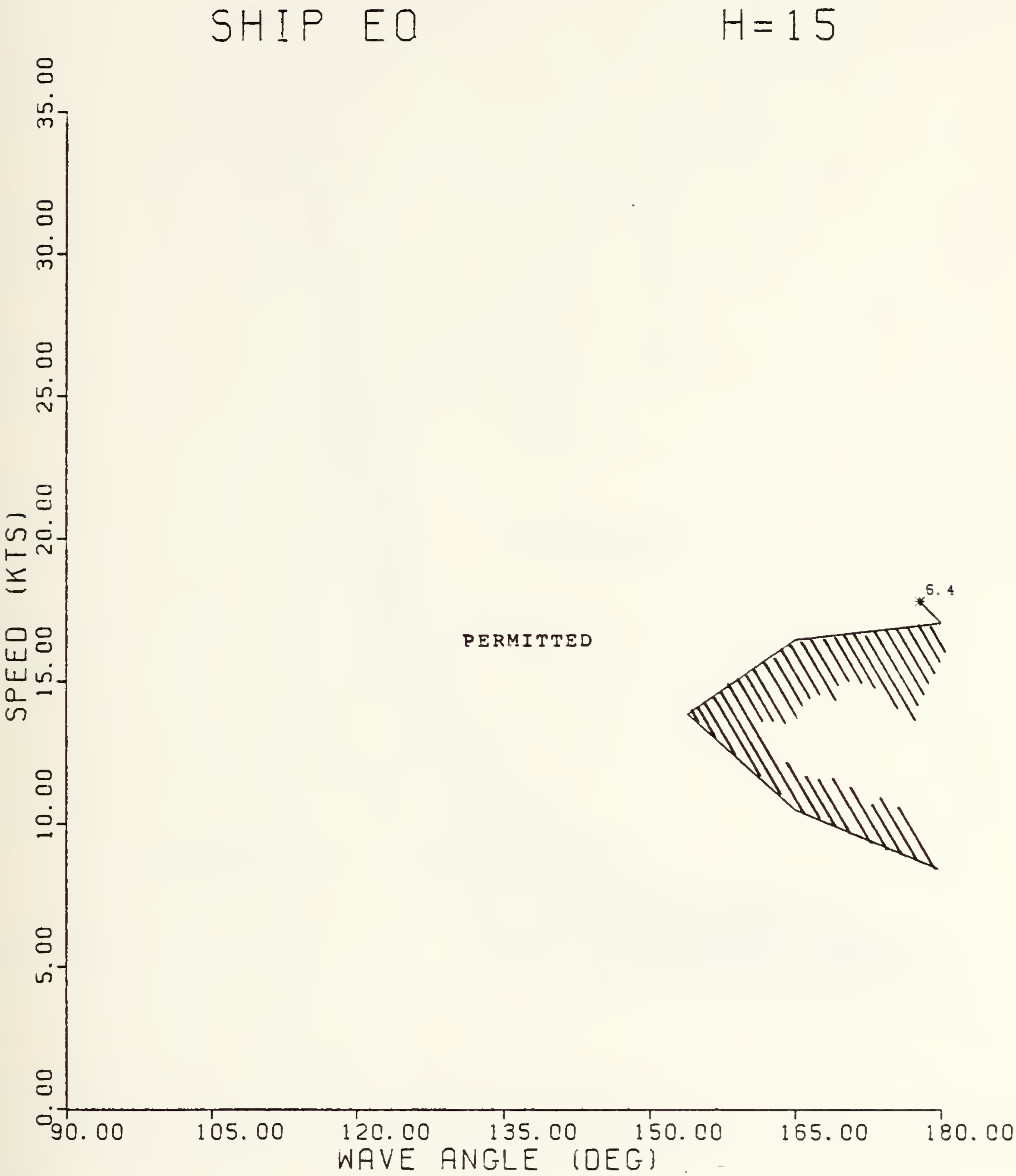


BØW ACCELERATION (FT/SEC²)
SHIP EO
H=25
MAX = 11.627
DOTTED LINE IS BELIEVED TO BE THE MOST PROBABLE CORRECT REPRESENTATION.
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

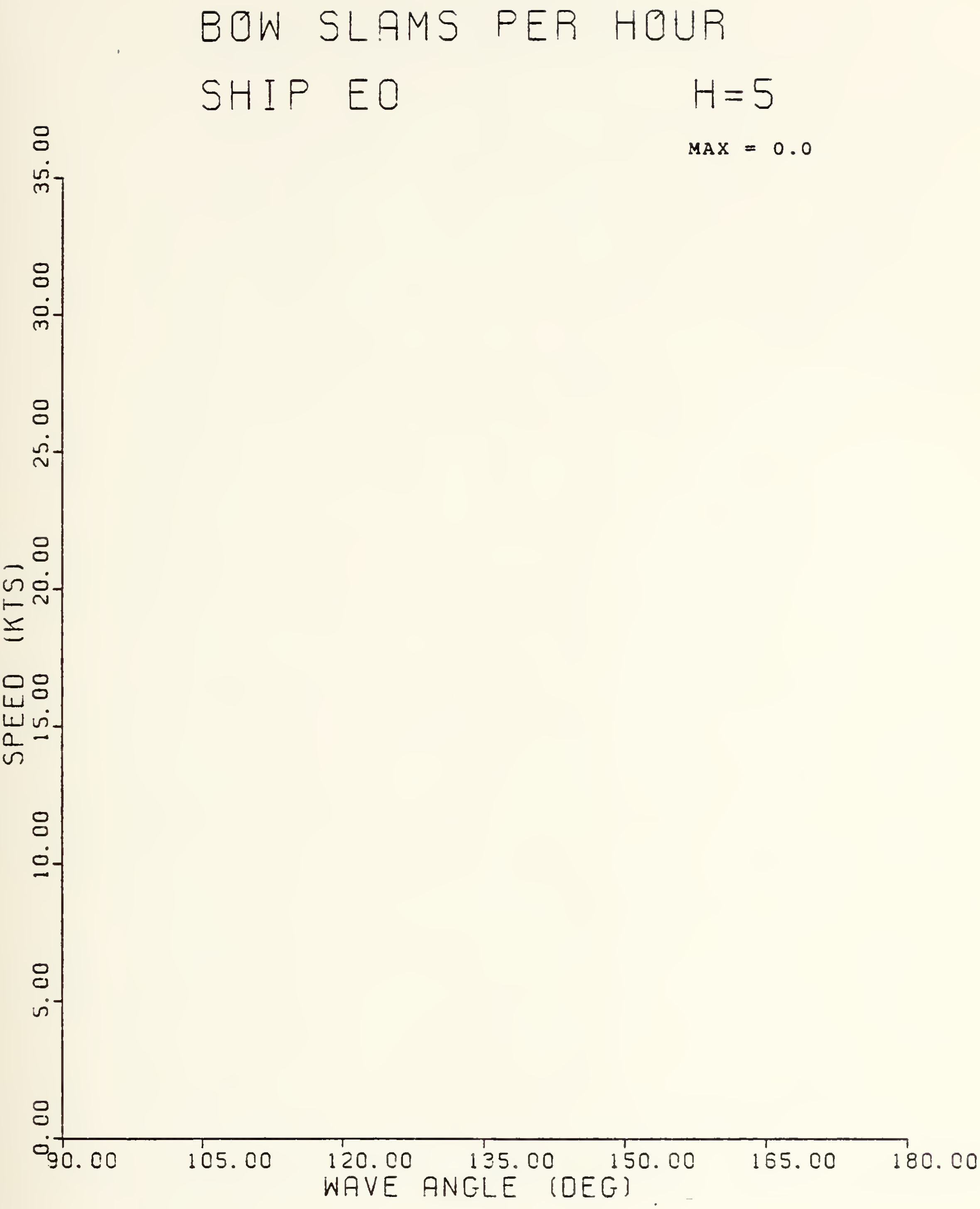
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2



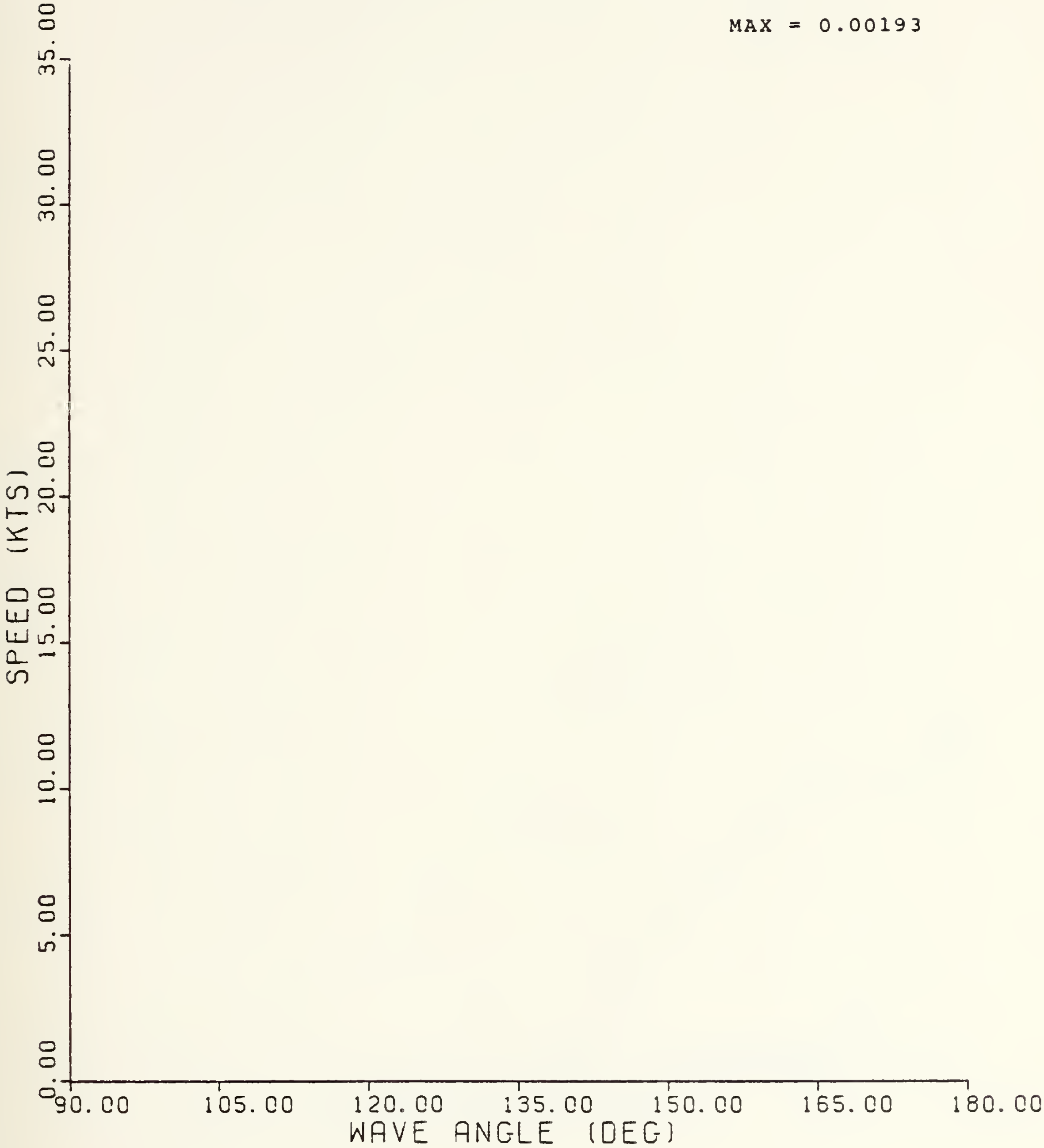
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

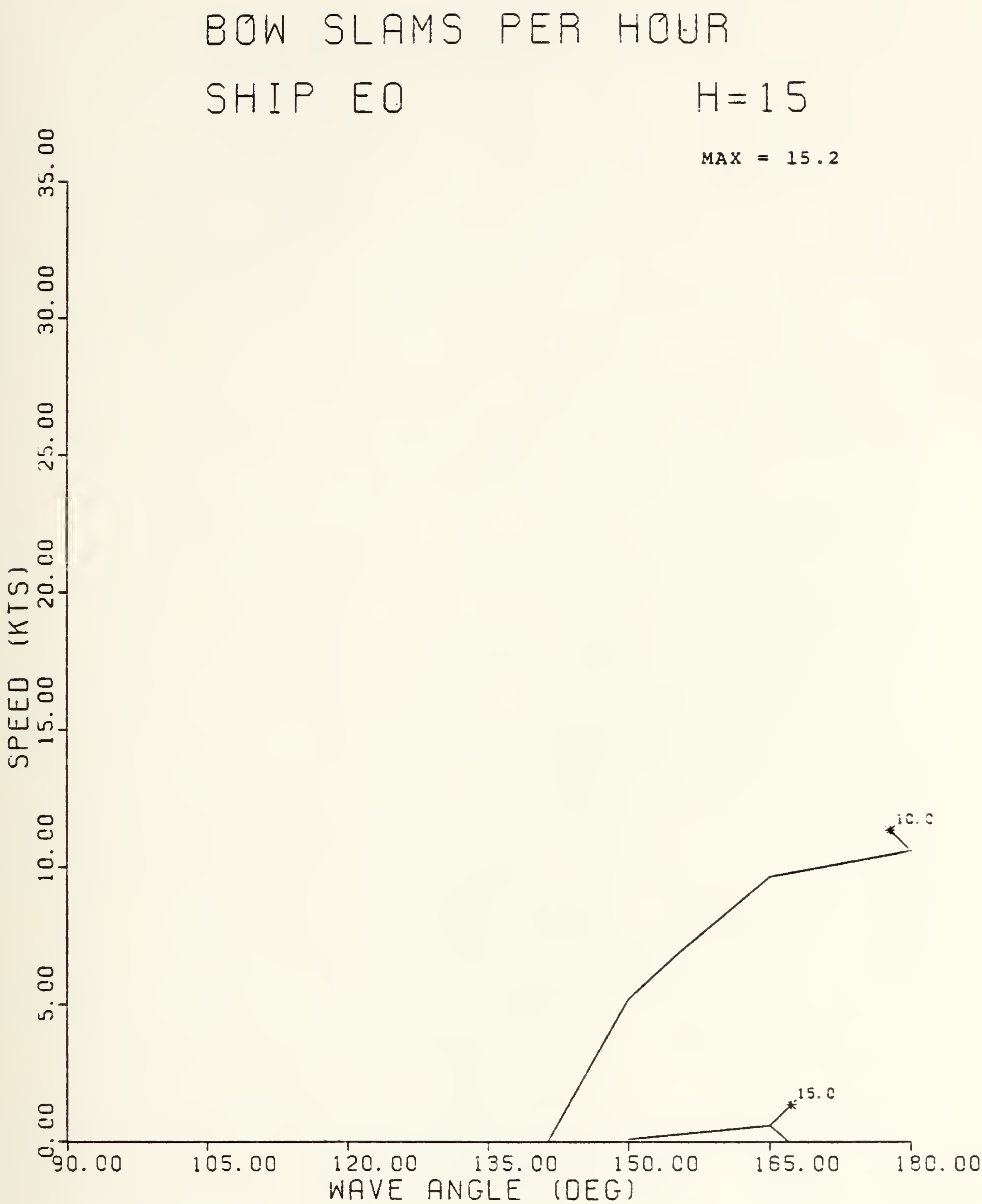
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2


BØW SLAMS PER HOUR
SHIP EO
H=5
MAX = 0.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

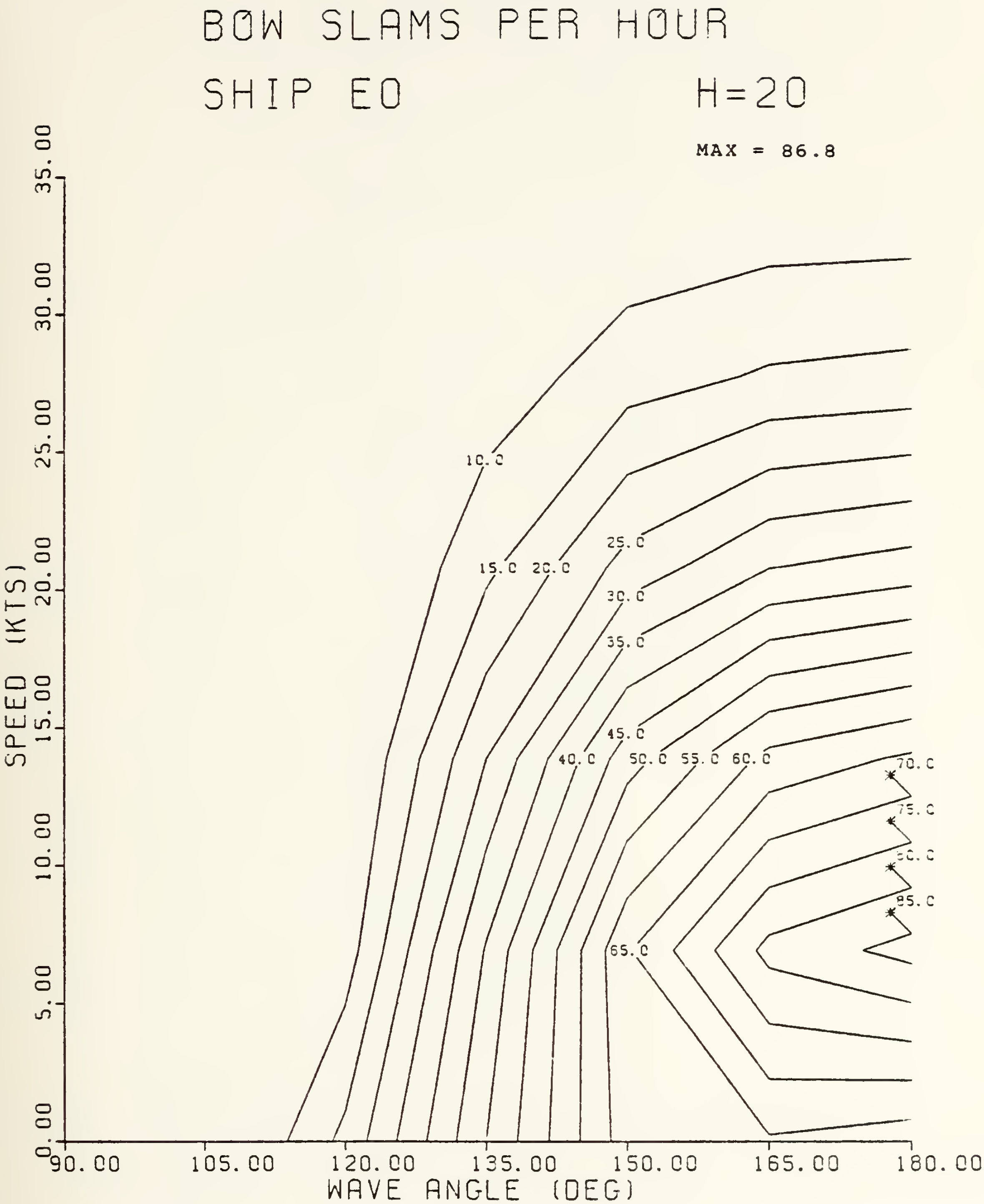
BOW SLAMS PER HOUR

SHIP EO H=10



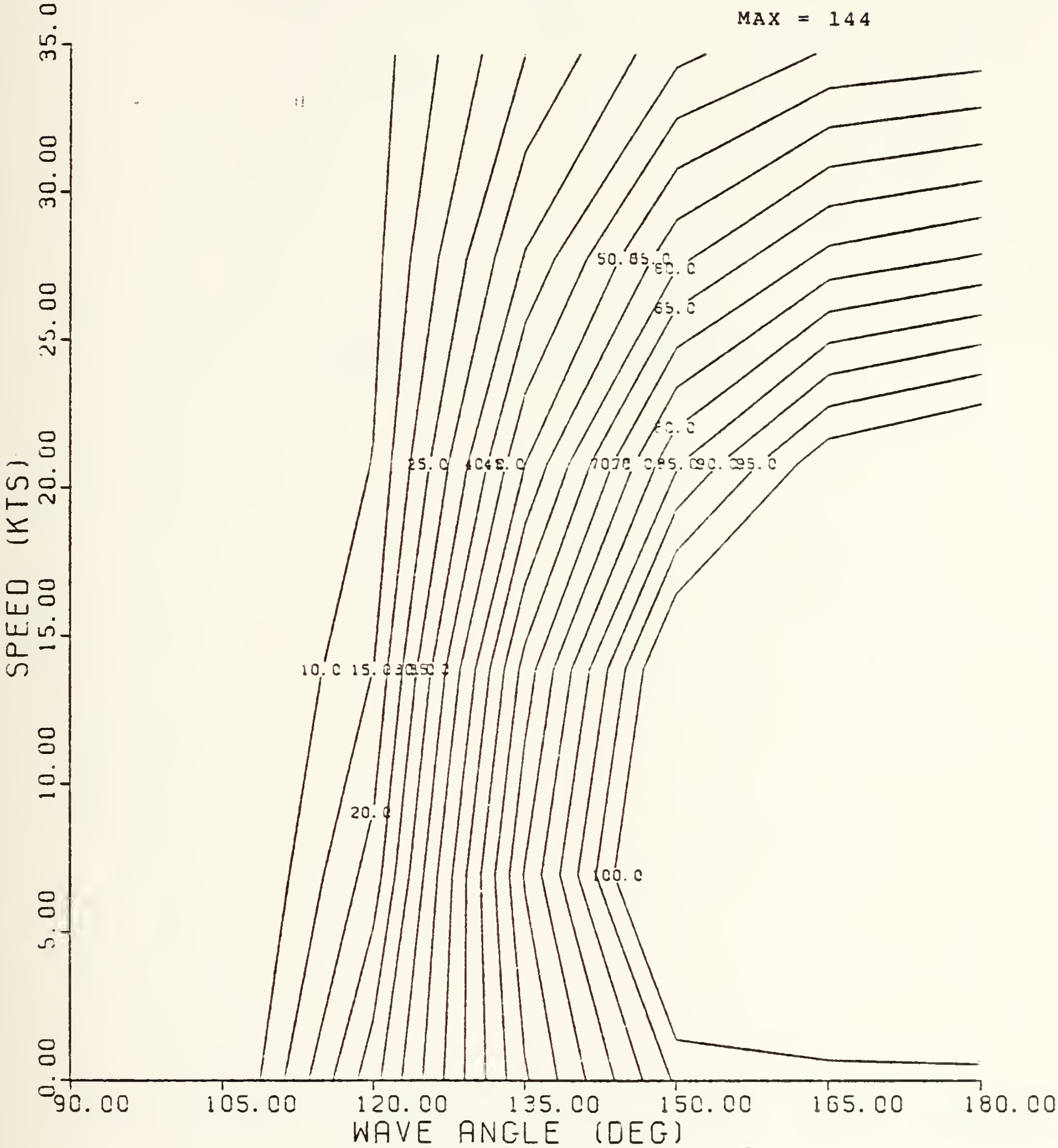


BOW SLAMS PER HOUR
SHIP EO
H=15
MAX = 15.2
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
WAVE ANGLE (DEG)
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0


BOW SLAMS PER HOUR
SHIP EO
H=20
MAX = 86.8
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
75.0
85.0

BØW SLAMS PER HOUR

SHIP EO H=25

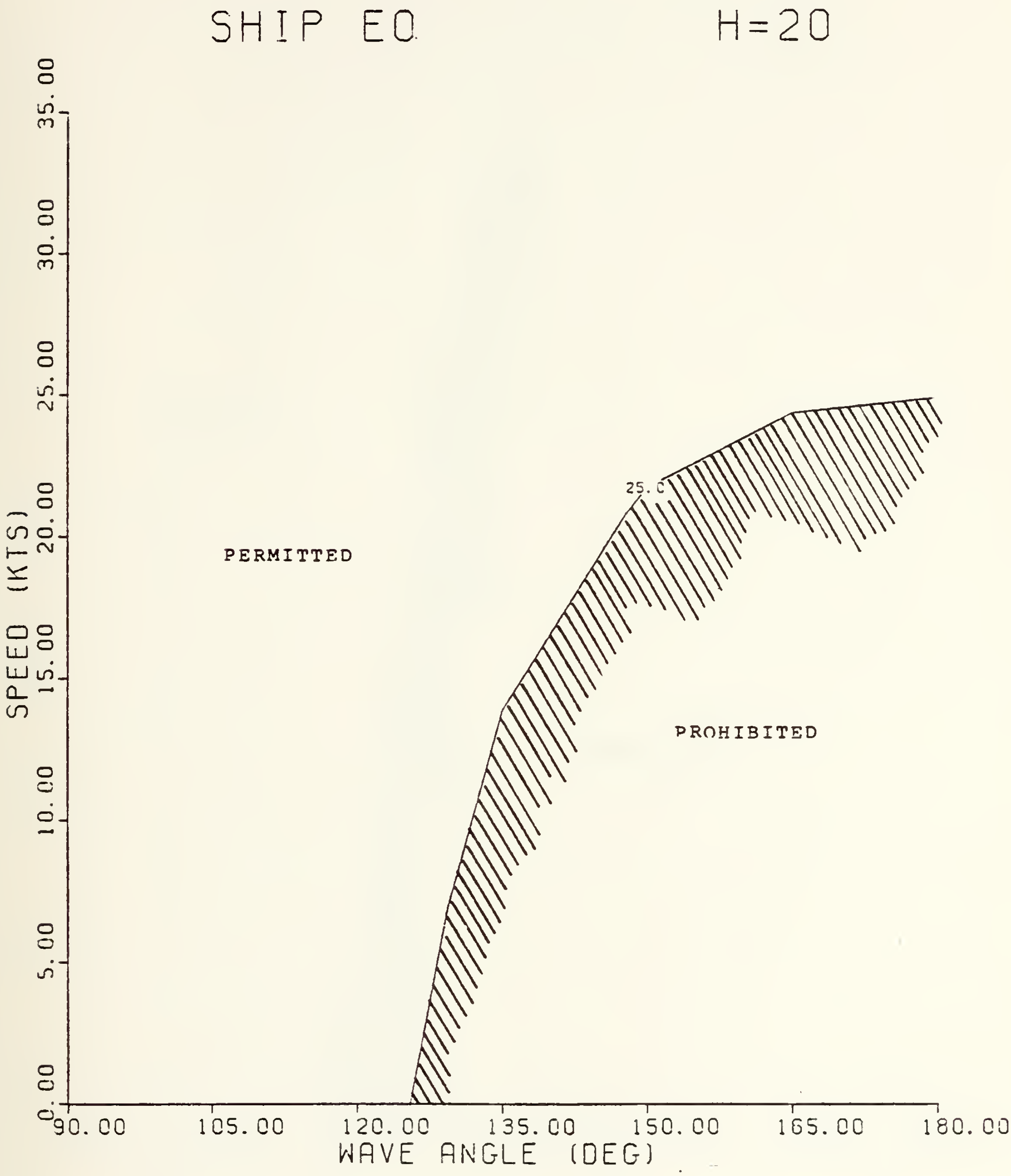


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

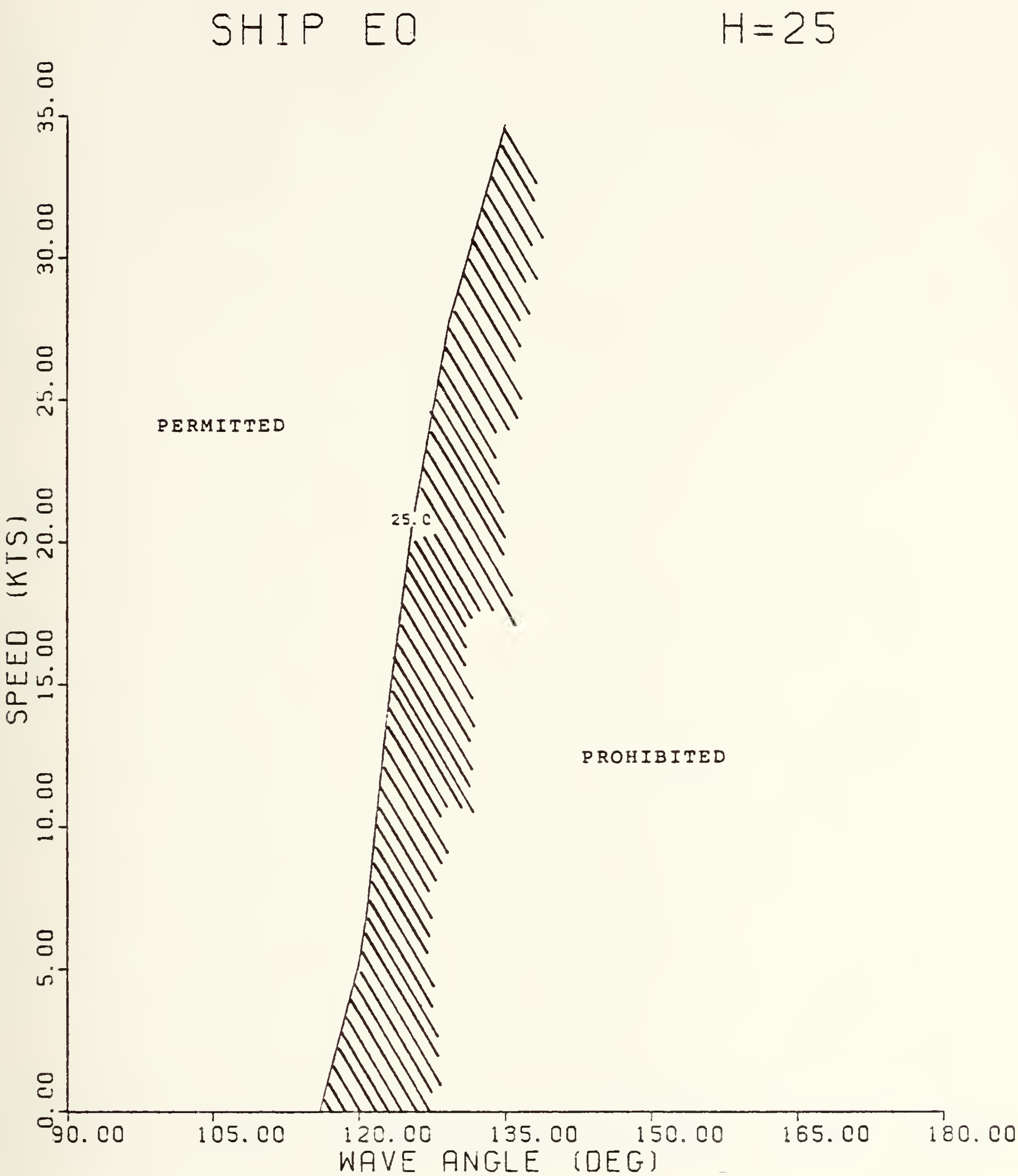
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

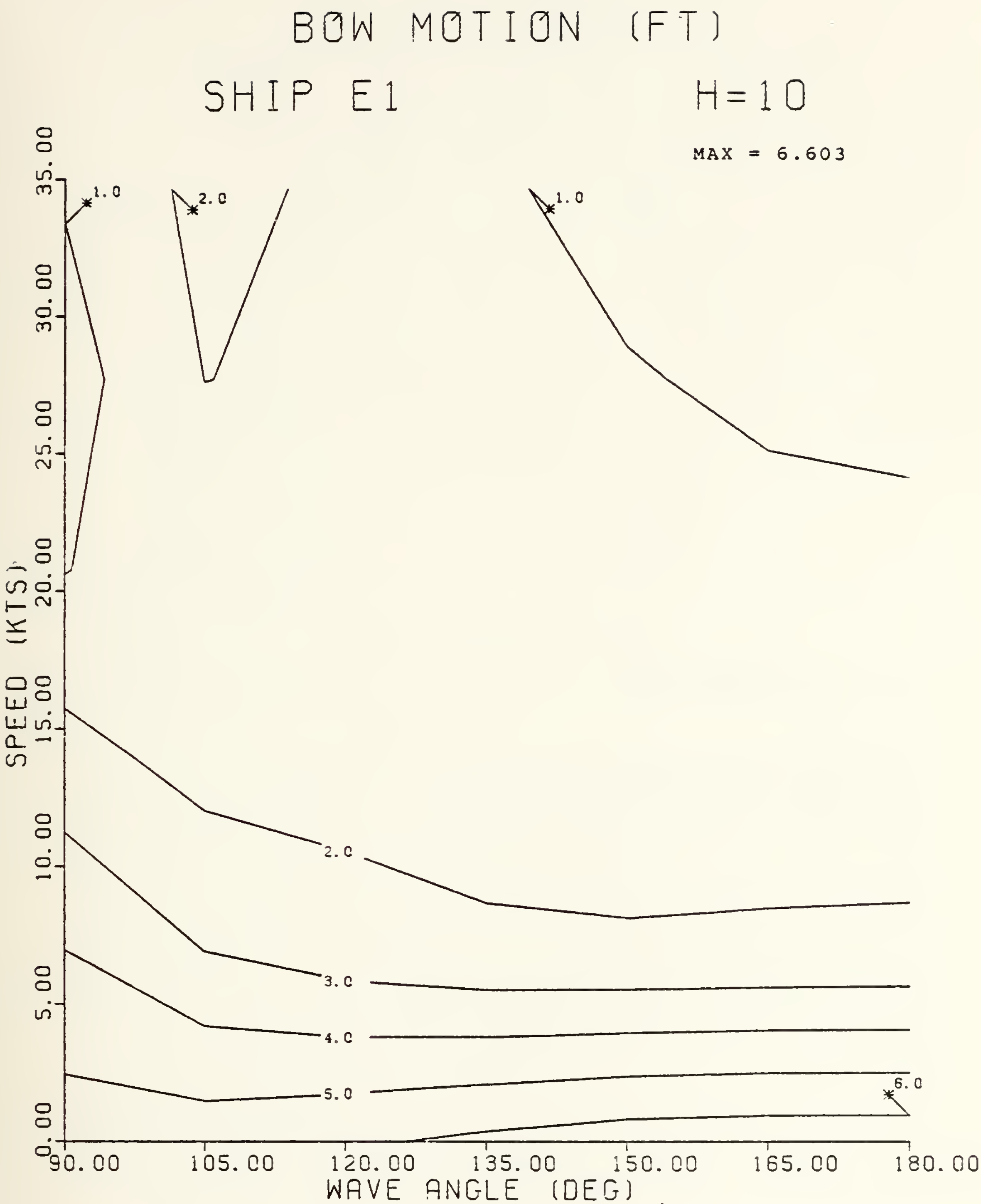
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

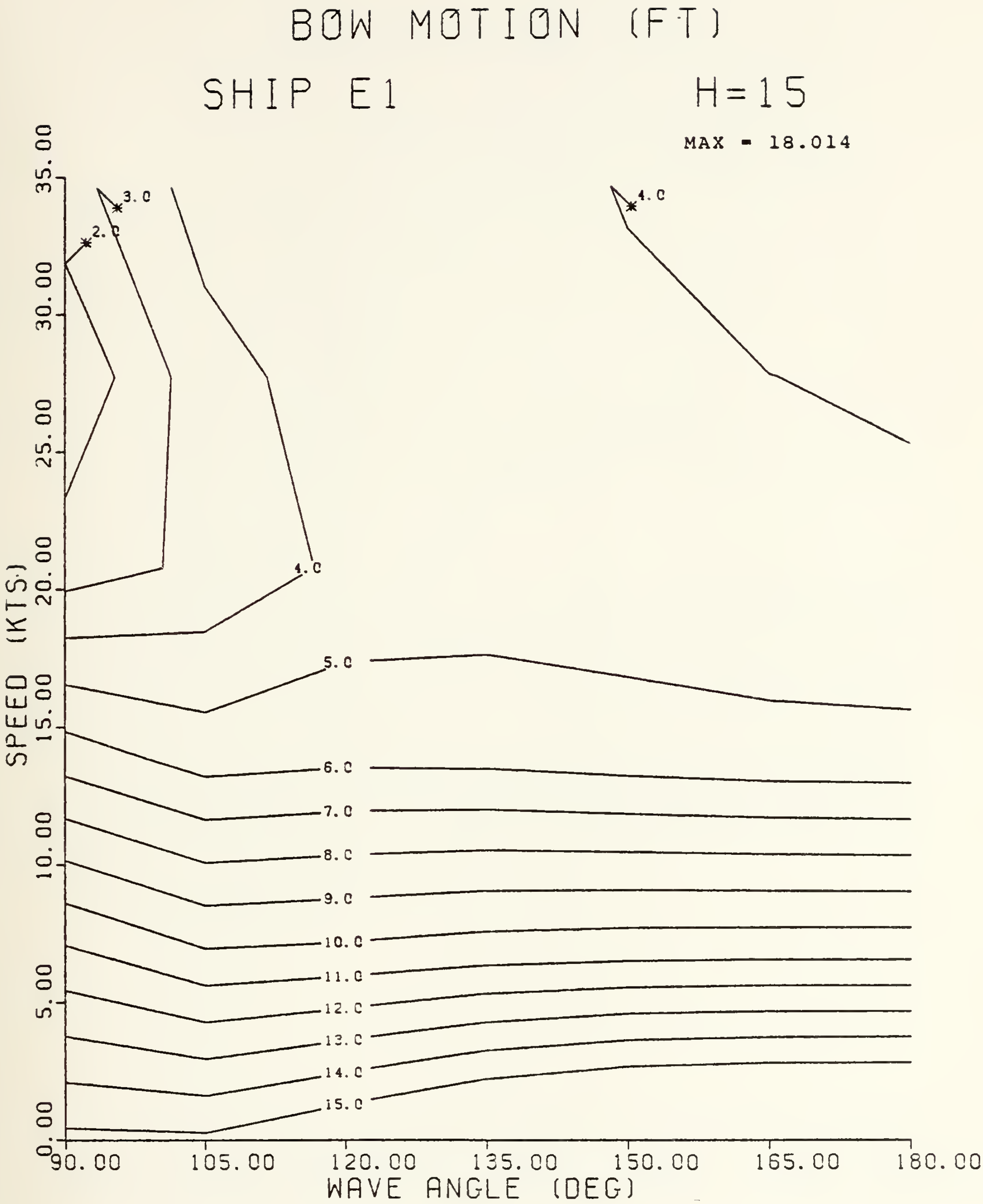


OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

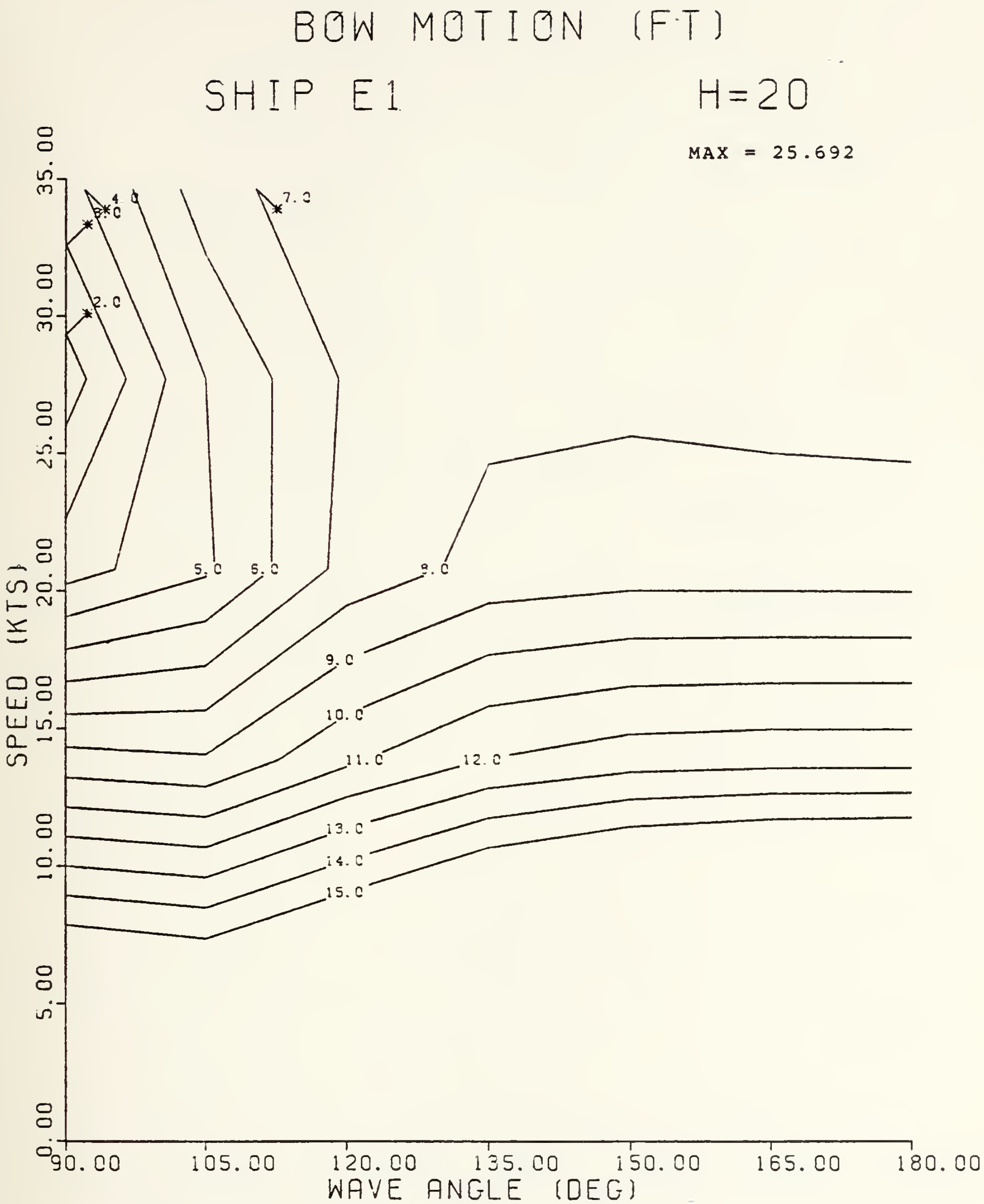


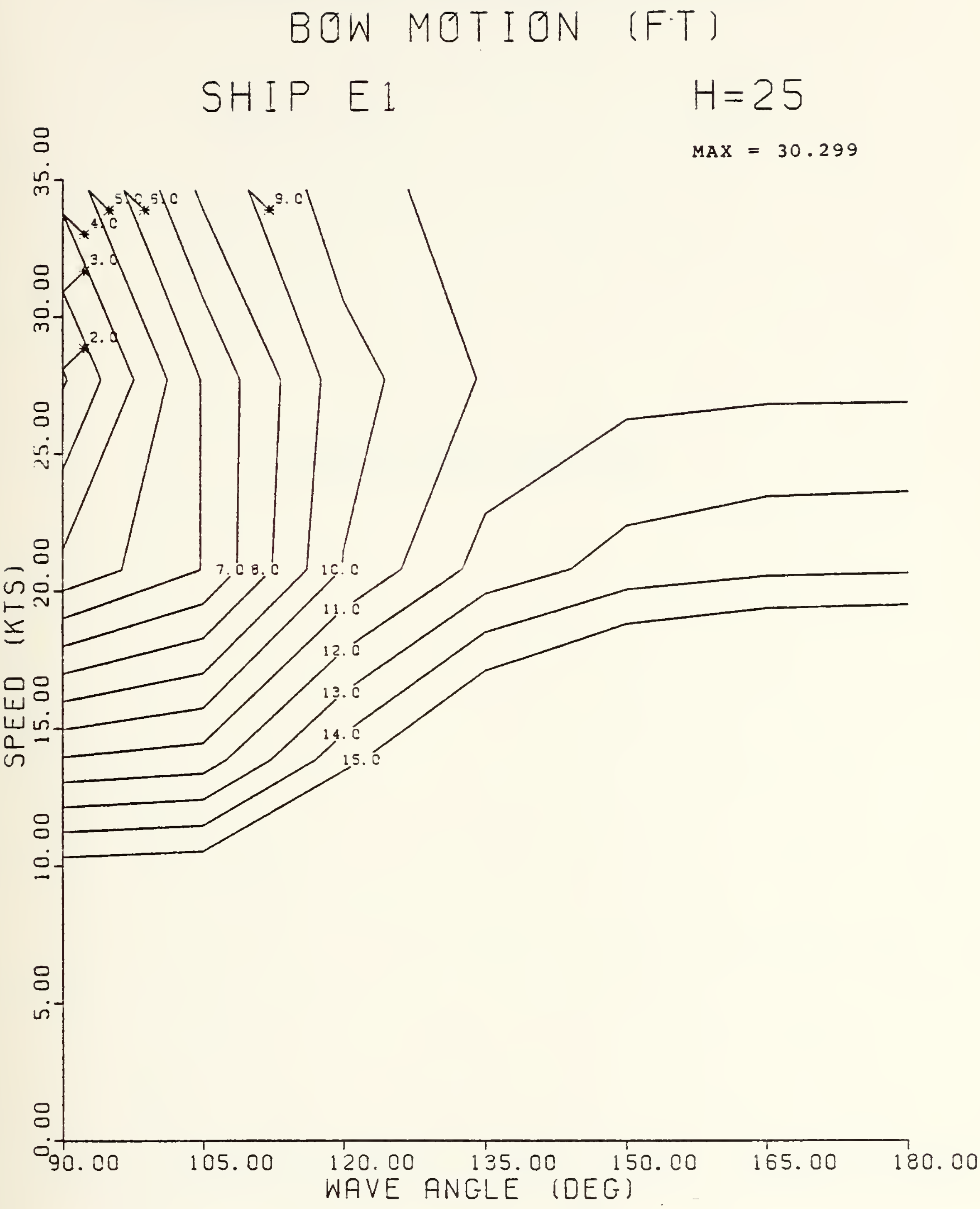
BOW MOTION (FT)
SHIP E1
H=5
MAX = 0.476
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW MOTION (FT)
SHIP E1
H=10
MAX = 6.603
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
1.0
2.0
1.0
2.0
3.0
4.0
5.0
6.0



BOW MOTION (FT)
SHIP E1
H=15
MAX = 18.014
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
2.0
3.0
4.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0

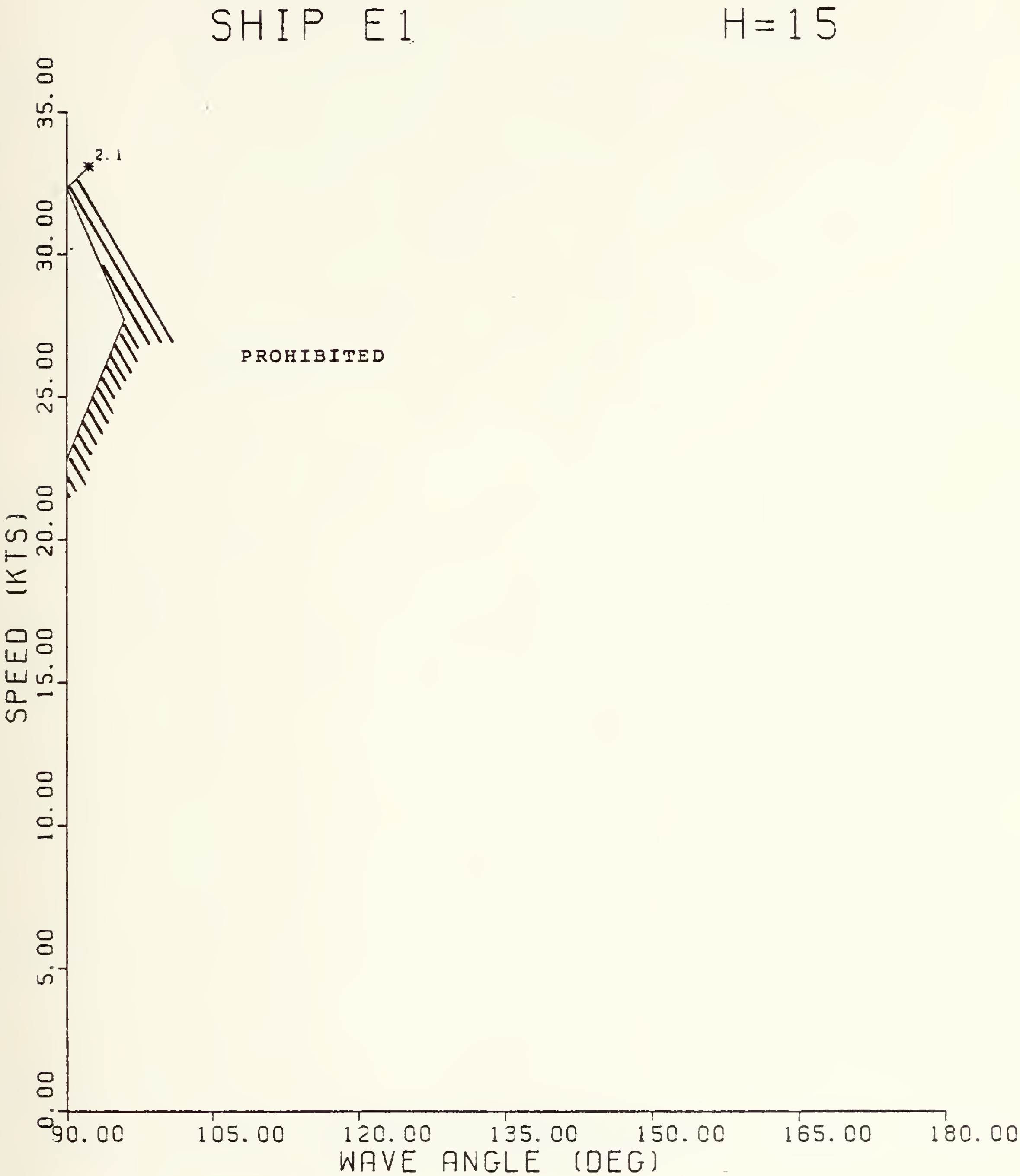

BØW MOTIØN (FT)
SHIP E1
H=20
MAX = 25.692
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0


BOW MOTION (FT)
SHIP E1
H=25
MAX = 30.299
2.0
3.0
4.0
5.0
5.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

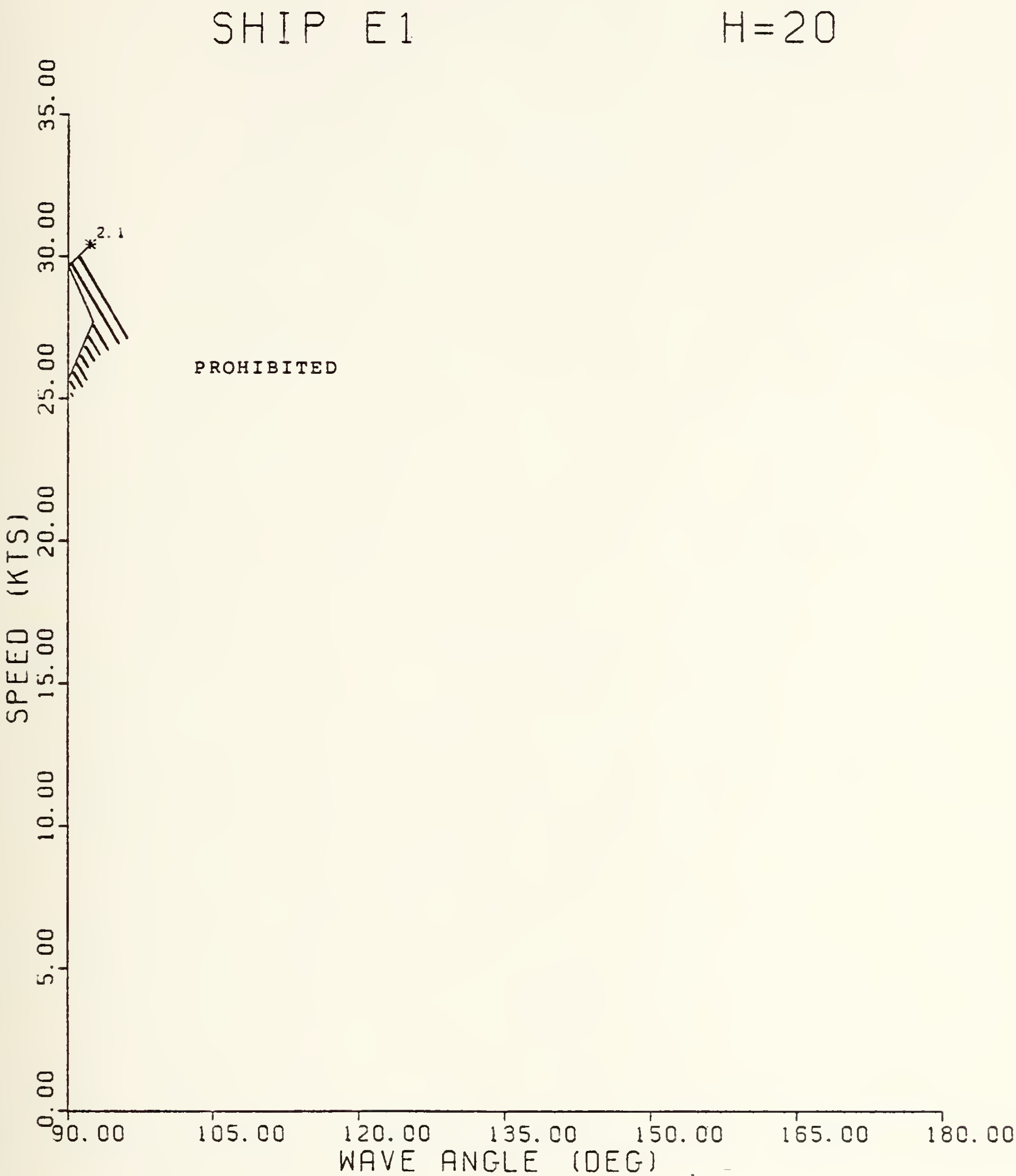
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

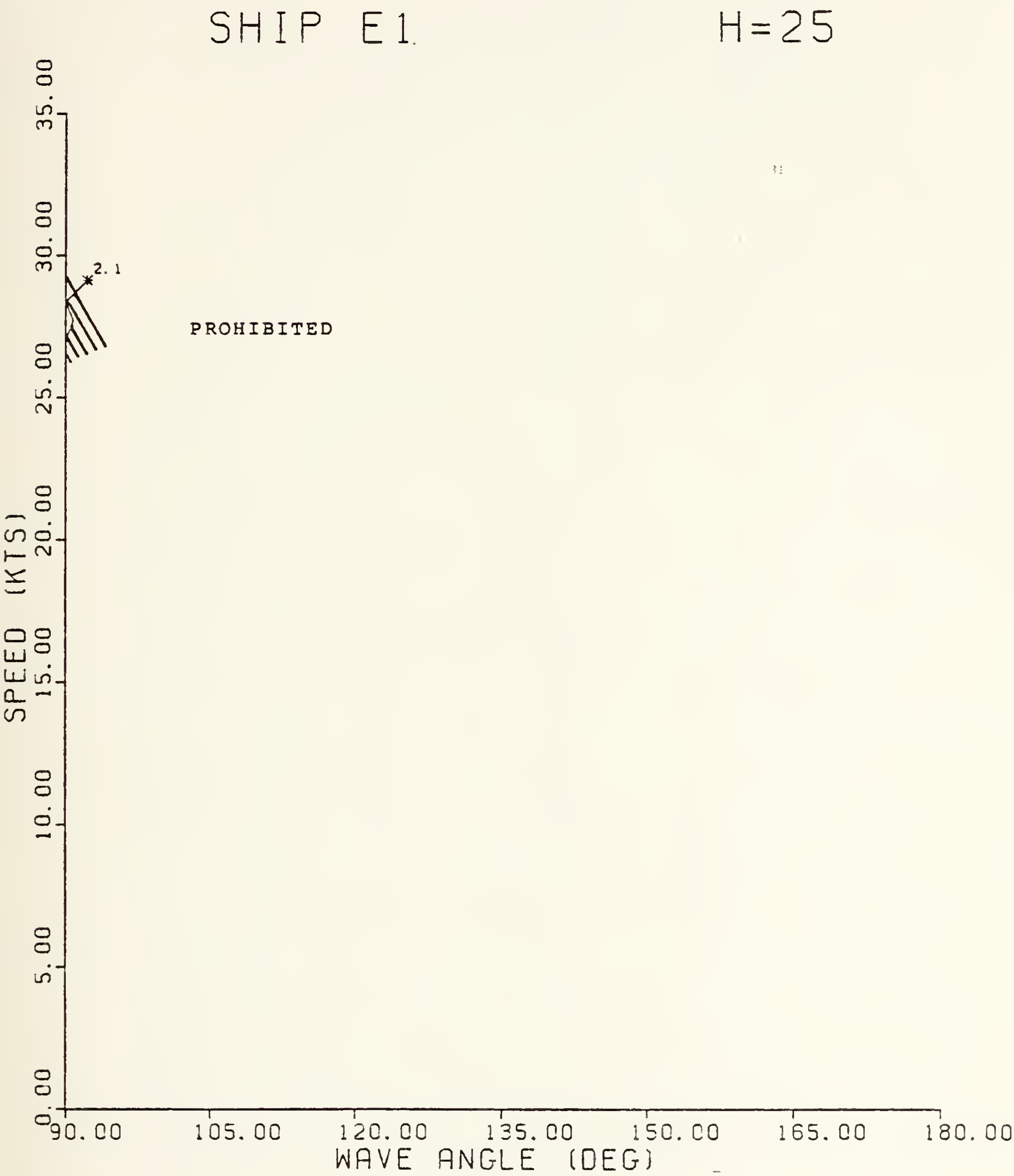
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET

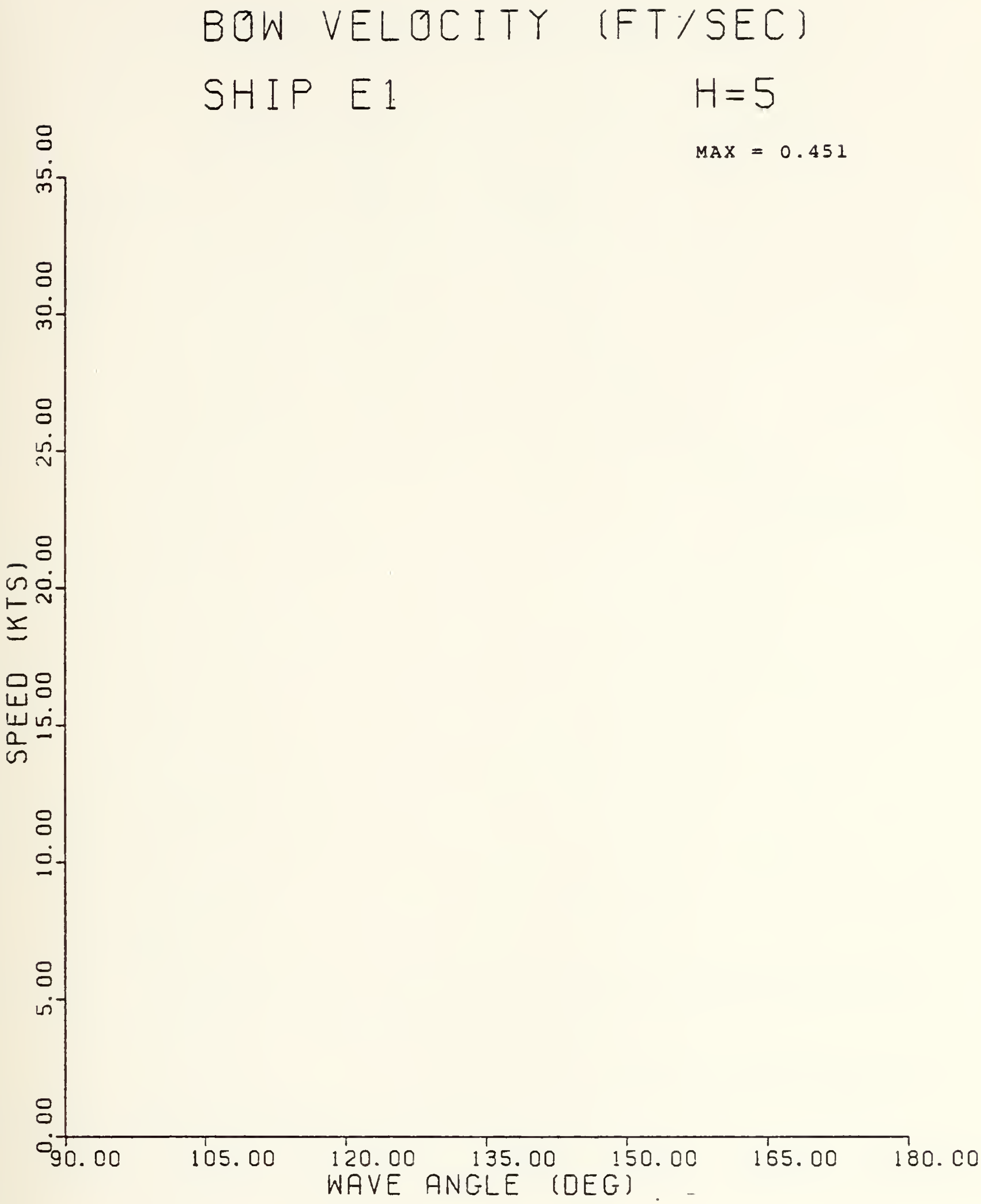


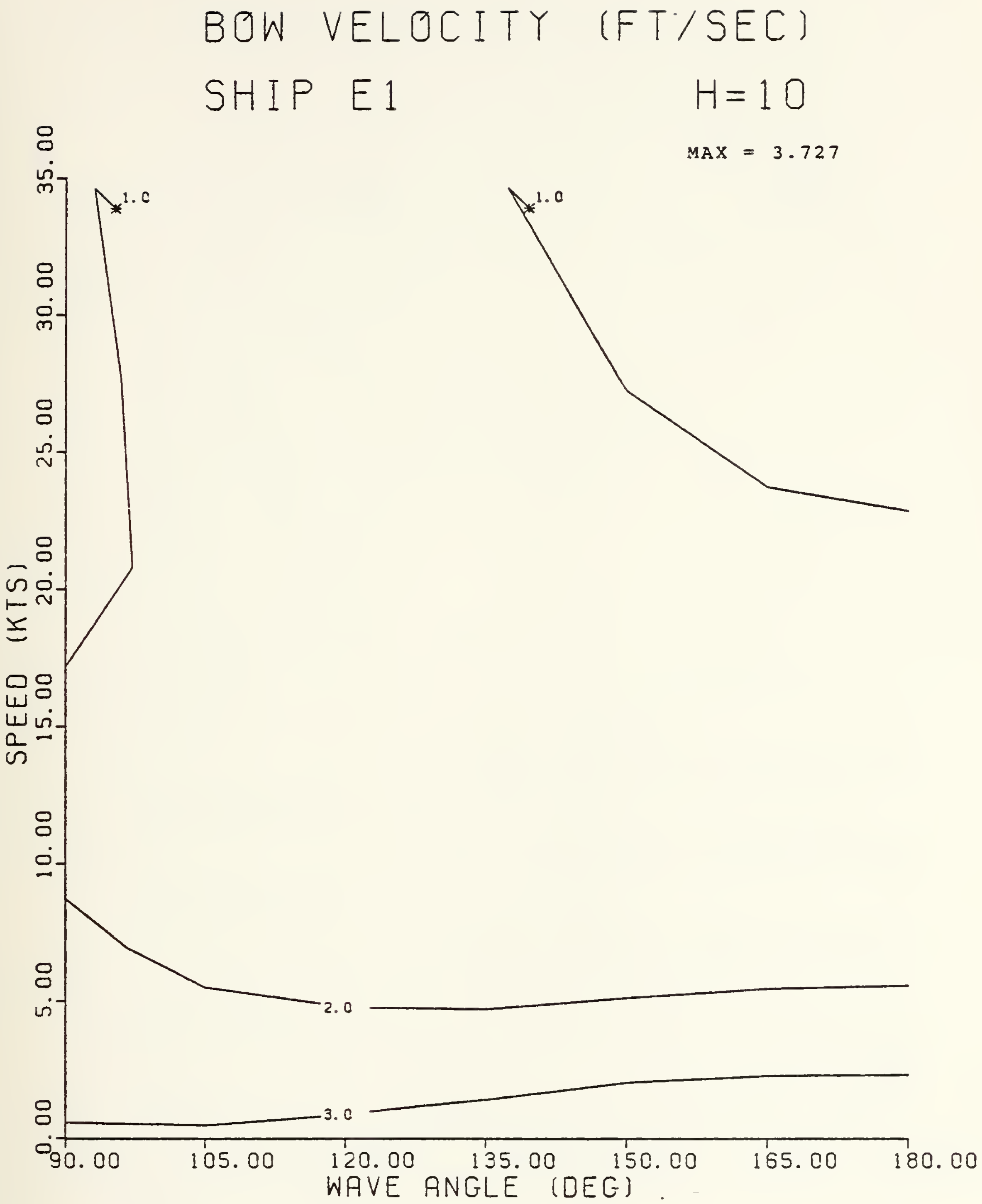
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET



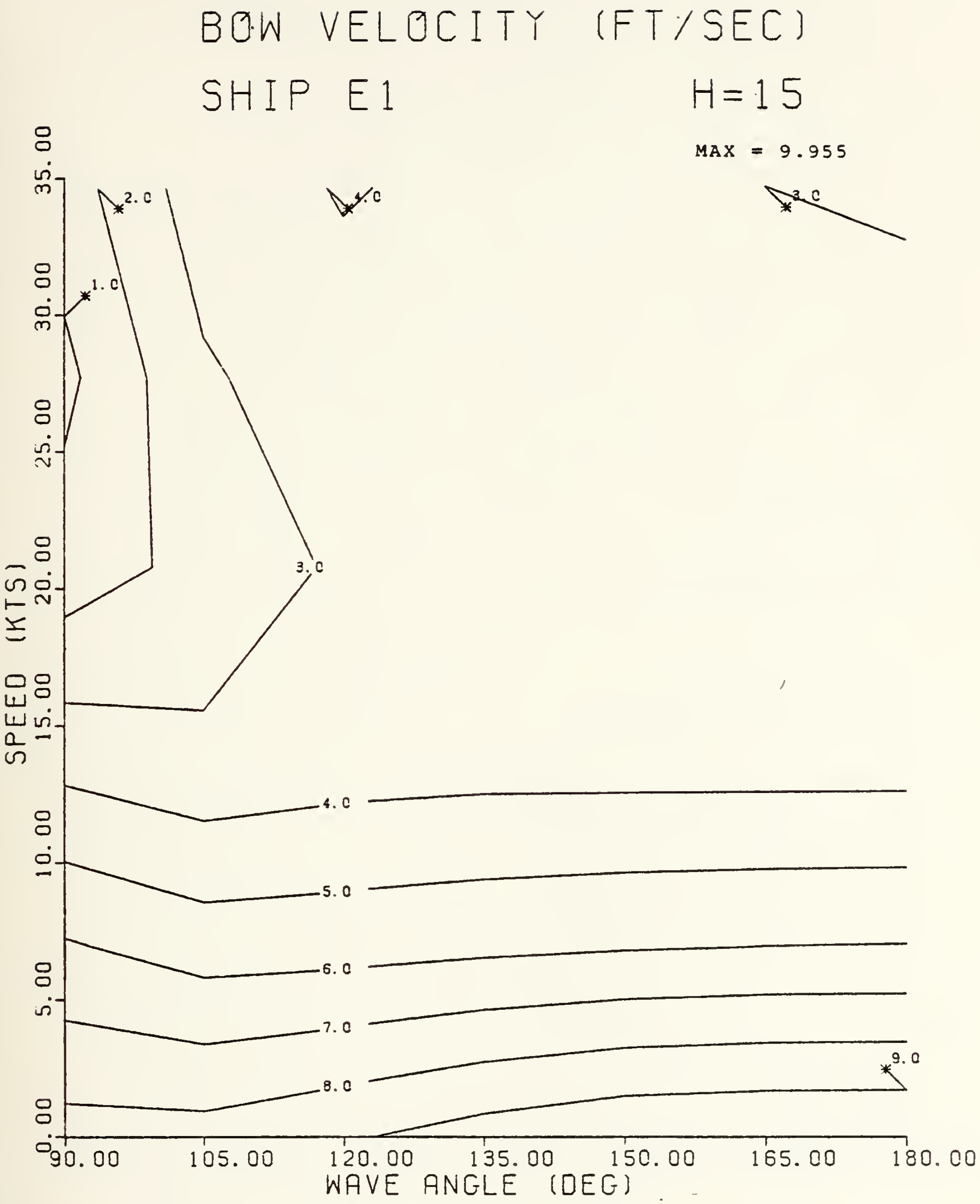
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW DISPLACEMENT OF 2.1 FEET



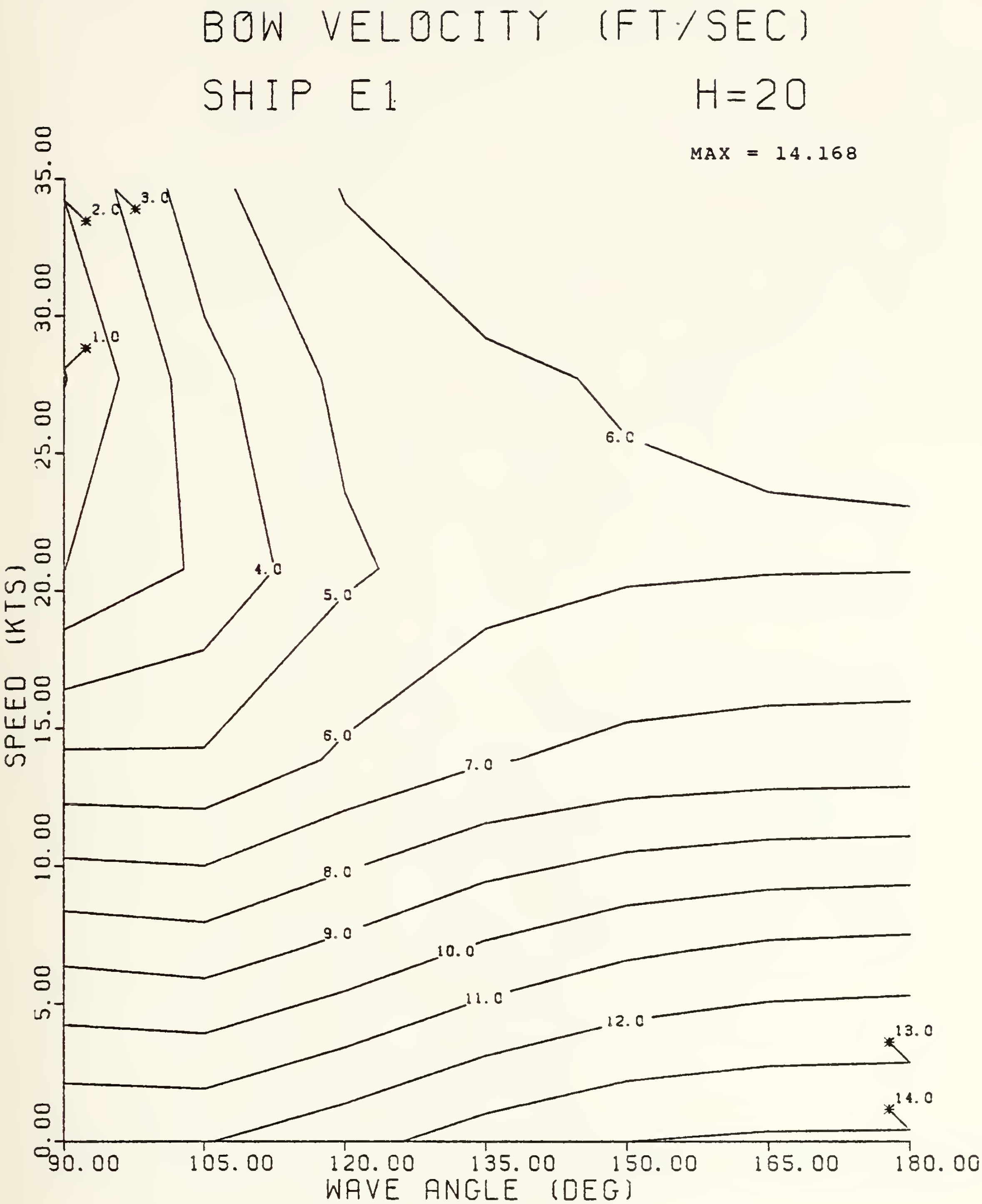

BØW VELØCITY (FT/SEC)
SHIP E1
H=5
MAX = 0.451
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



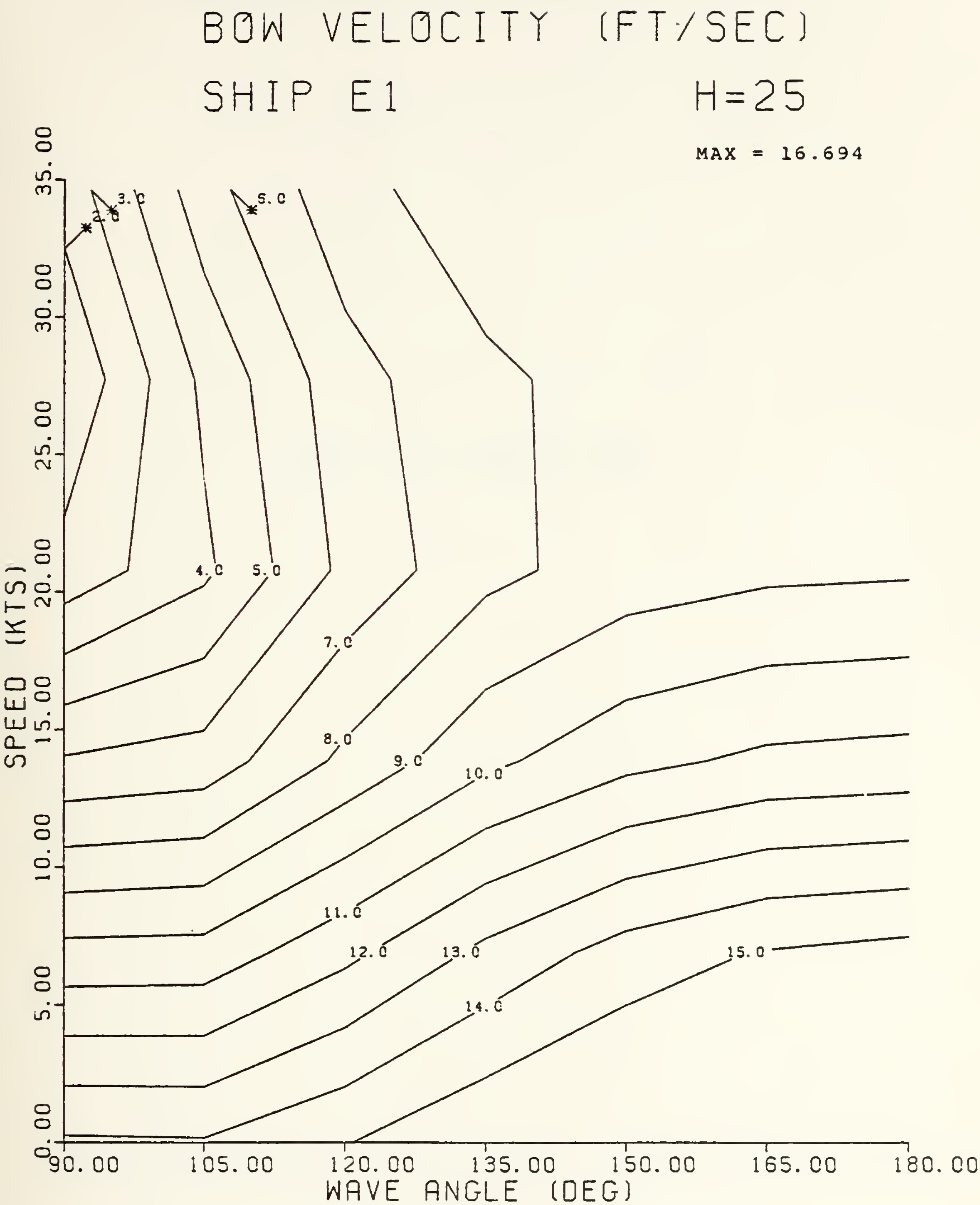
BOW VELOCITY (FT/SEC)
SHIP E1
H=10
MAX = 3.727
1.0
1.0
2.0
3.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BØW VELOCITY (FT/SEC)
SHIP E1
H=15
MAX = 9.955
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0



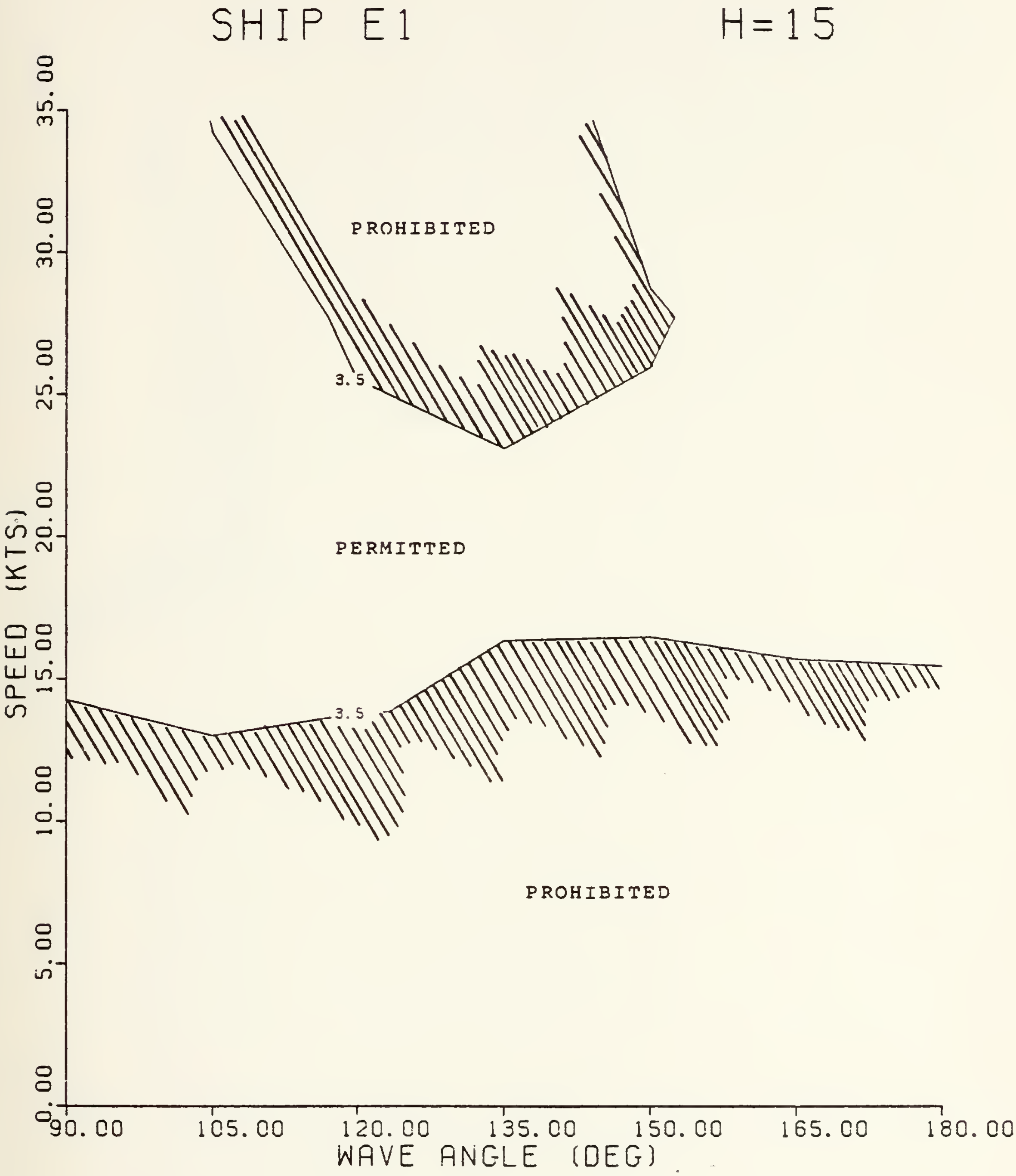
BØW VELOCITY (FT/SEC)
SHIP E1 H=20
MAX = 14.168
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0


BØW VELØCITY (FT/SEC)
SHIP E1
H=25
MAX = 16.694
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

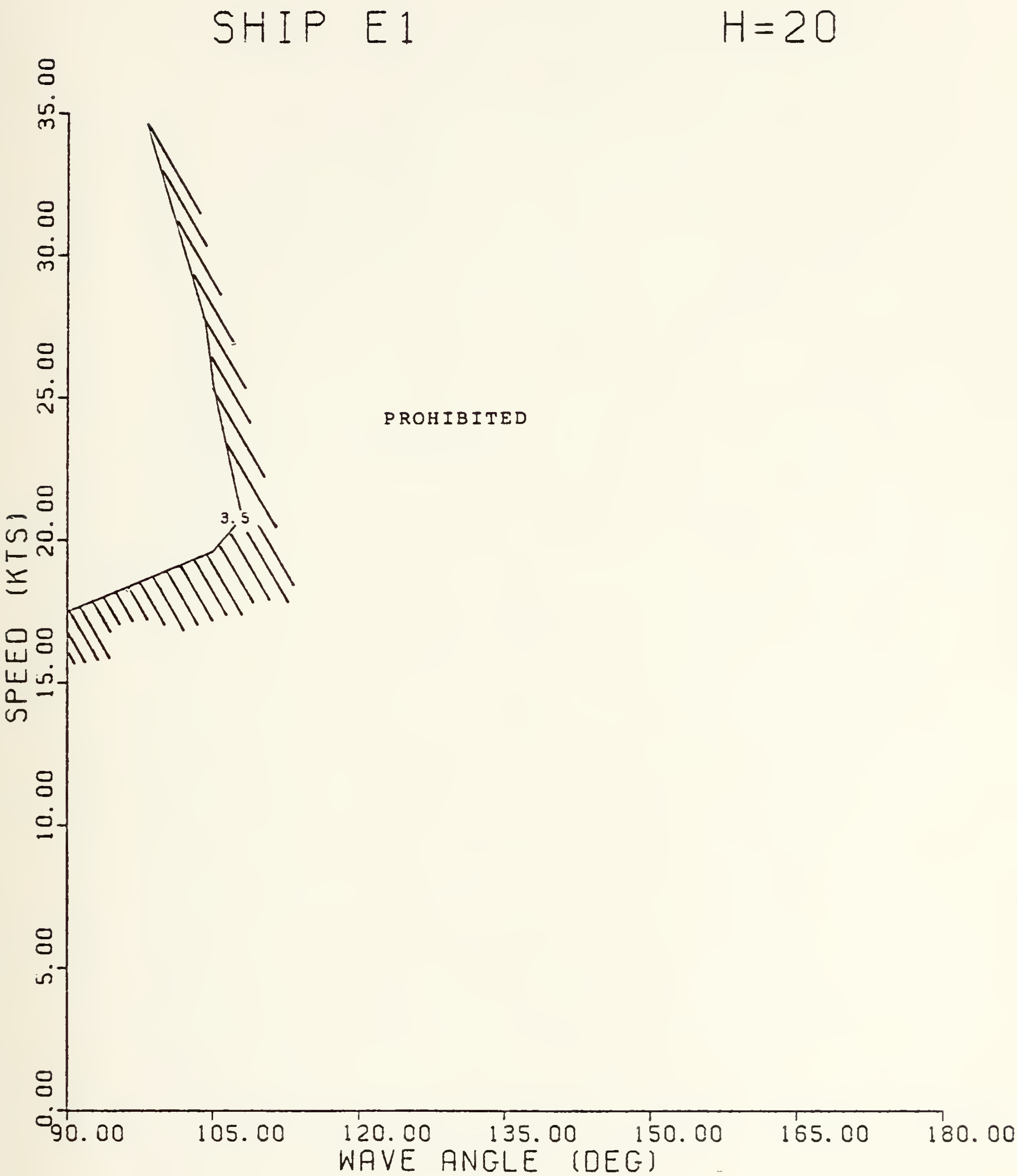
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

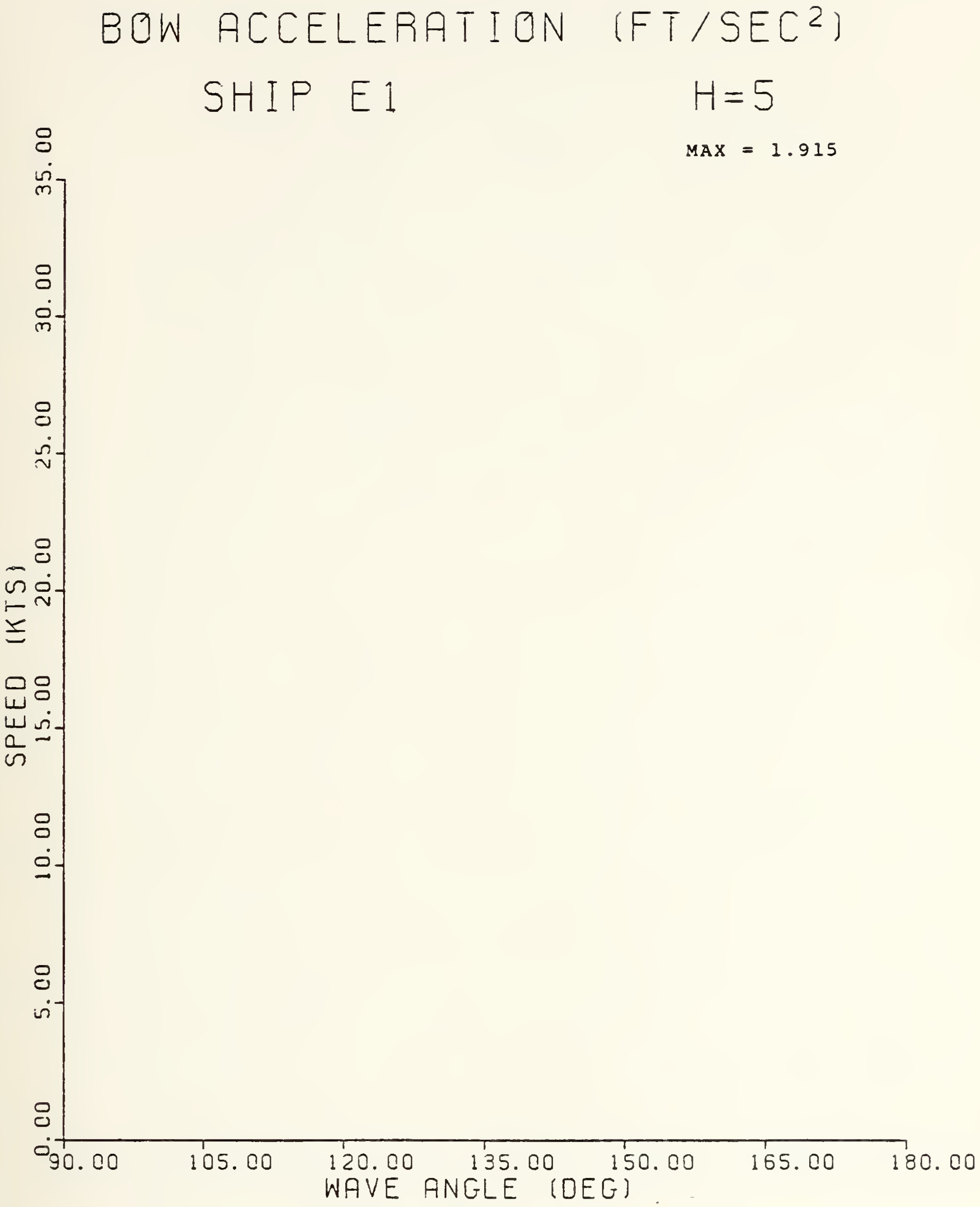
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC



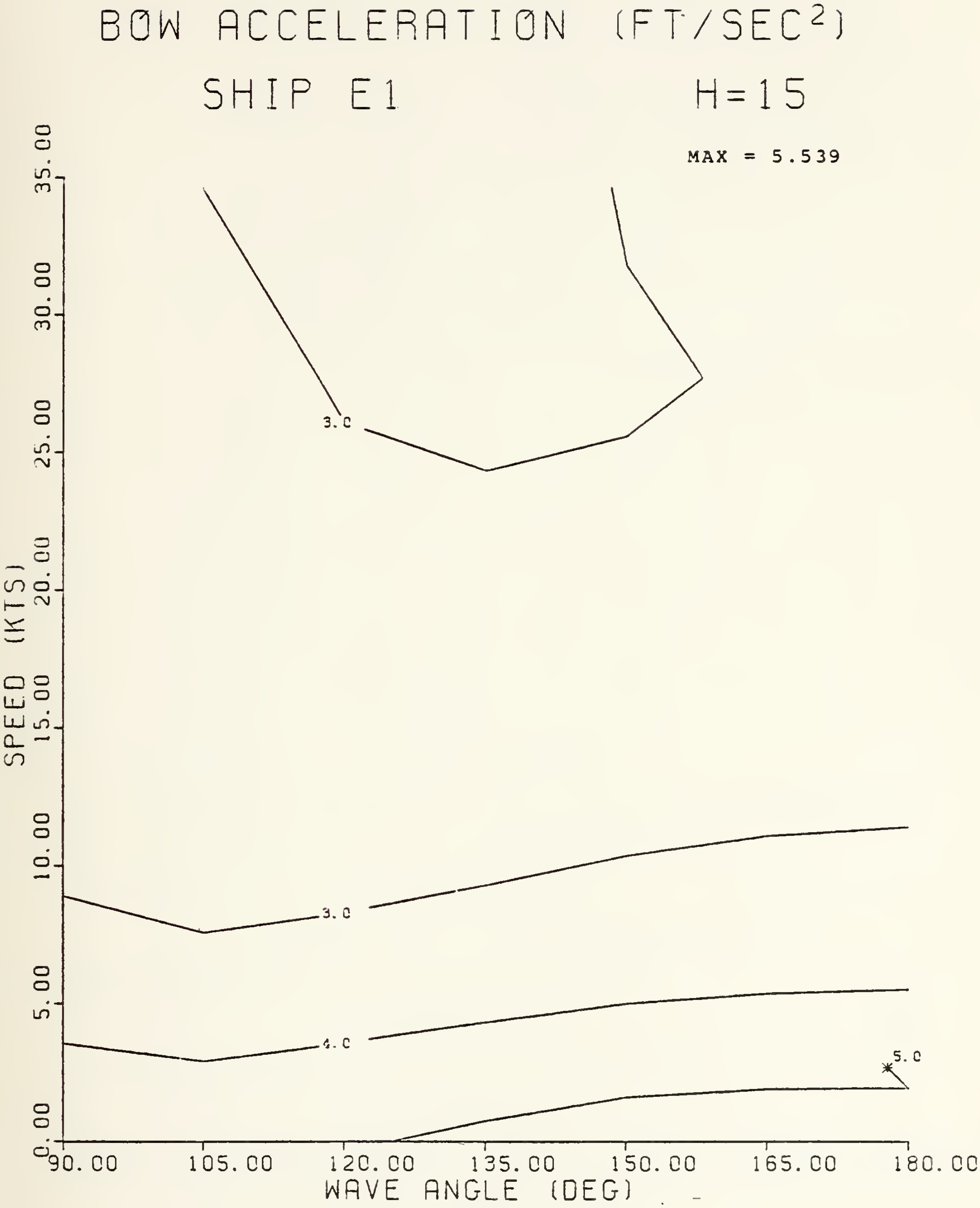
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC



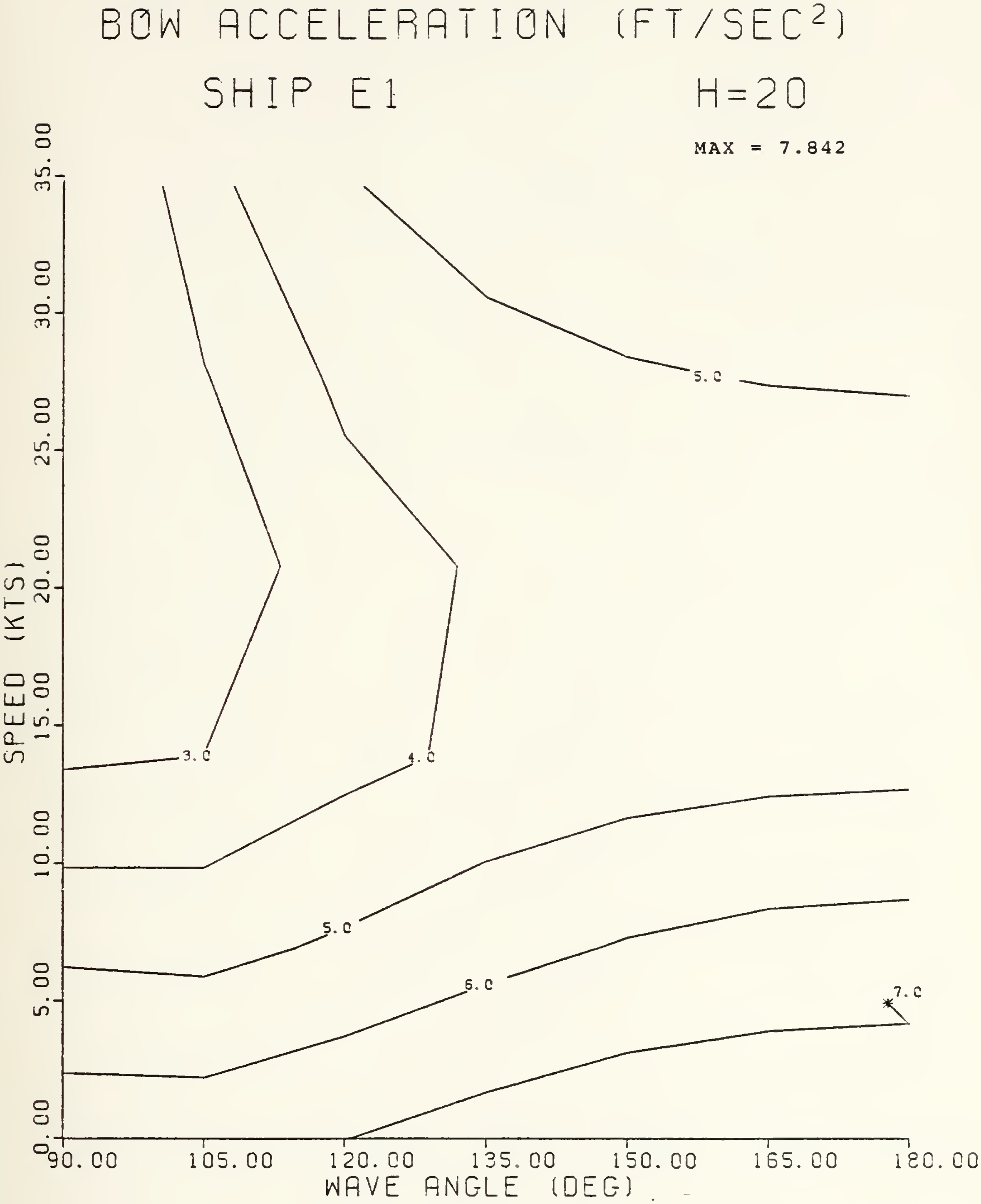
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW VELOCITY OF 3.5 FT/SEC

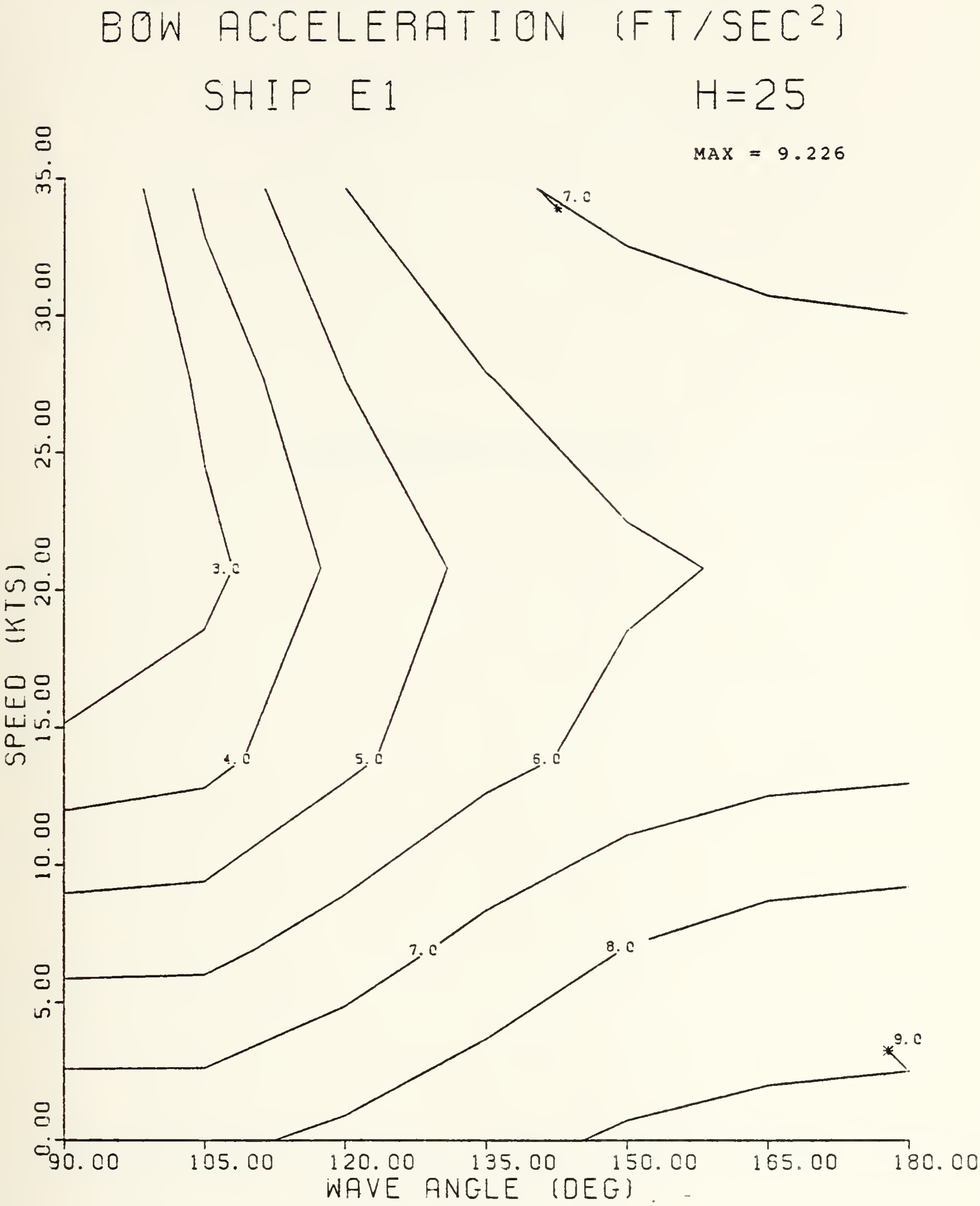

BOW ACCELERATION (FT/SEC²)
SHIP E1
H=5
MAX = 1.915
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BØW ACCELERATIØN (FT/SEC²)
SHIP E1
H=10
MAX = 2.172
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BOW ACCELERATION (FT/SEC²)
SHIP E1
H=15
MAX = 5.539
3.0
3.0
4.0
5.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)


BOW ACCELERATION (FT/SEC²)
SHIP E1
H=20
MAX = 7.842
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)
3.0
4.0
5.0
5.0
6.0
7.0

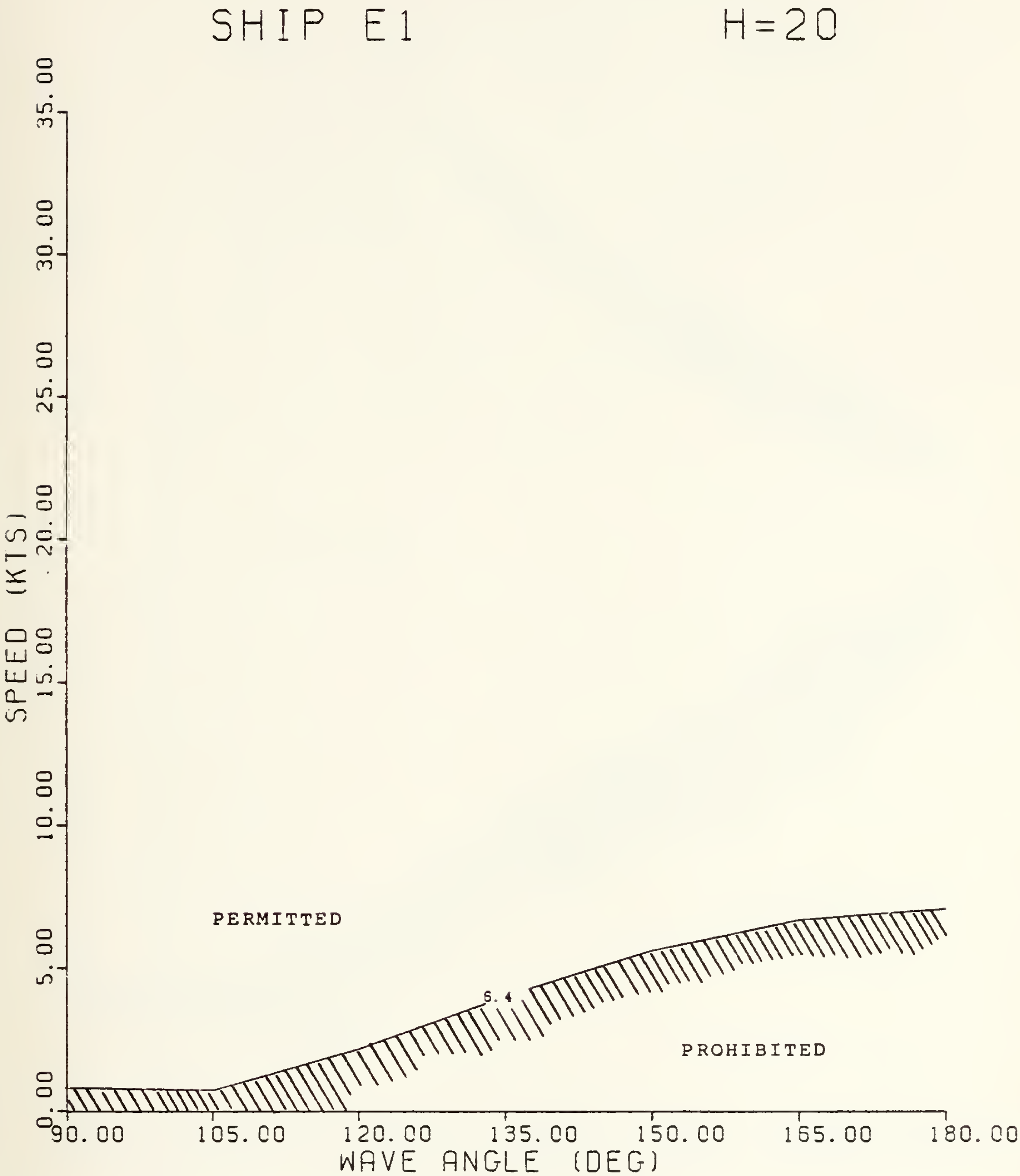

BOW ACCELERATION (FT/SEC2)
SHIP E1
H=25
MAX = 9.226
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
3.0
4.0
5.0
6.0
7.0
8.0
9.0

OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

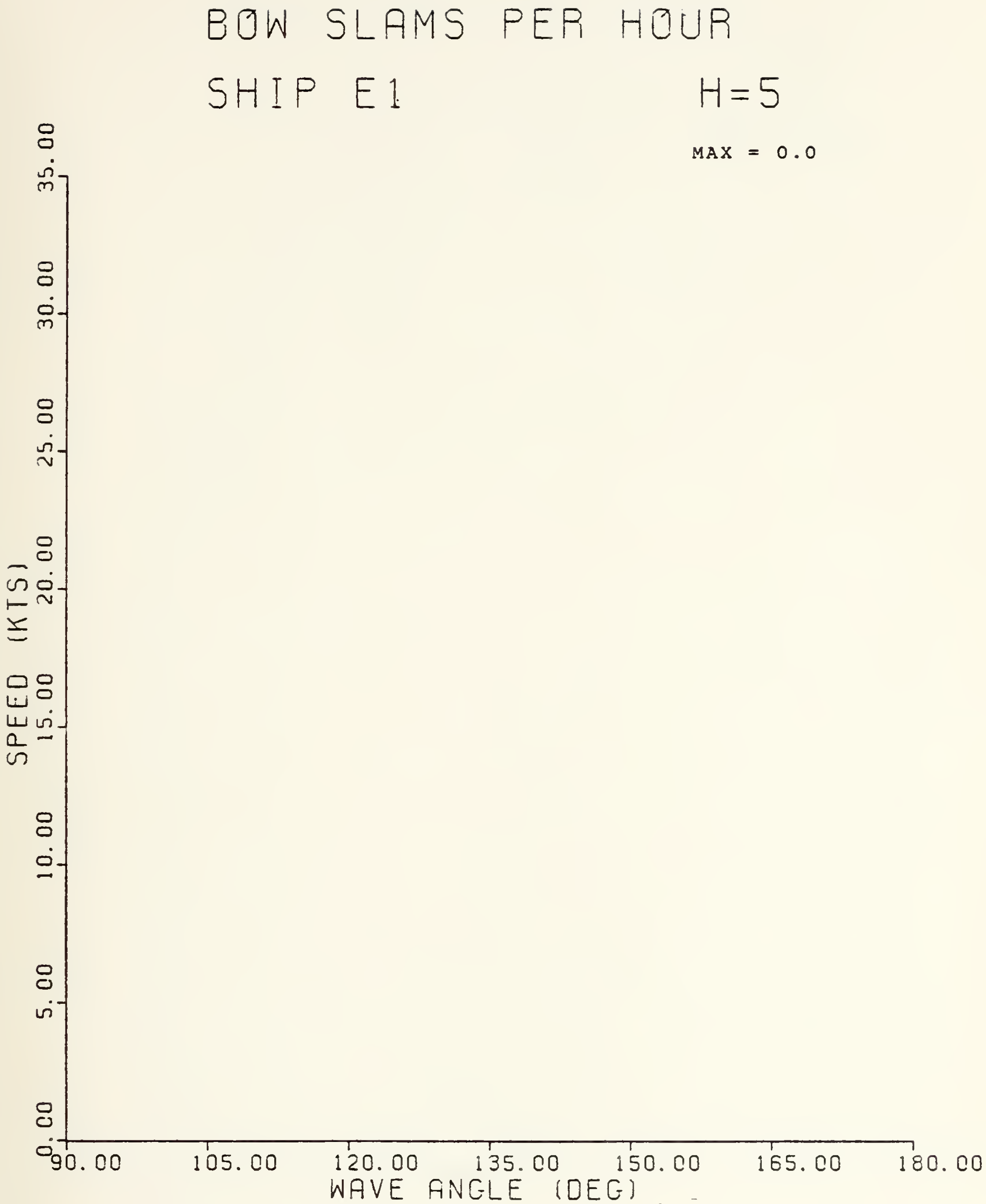
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC²

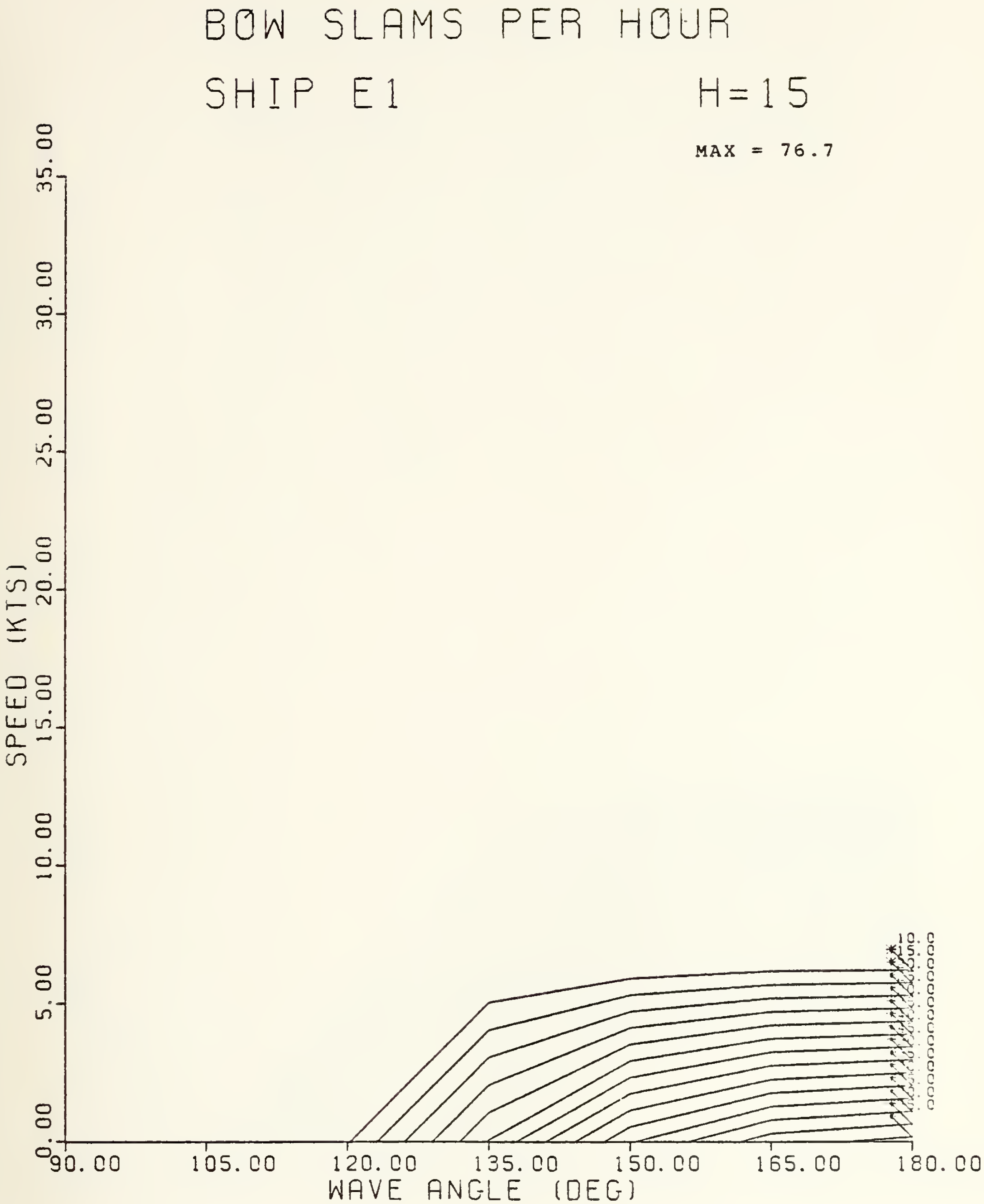
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC²



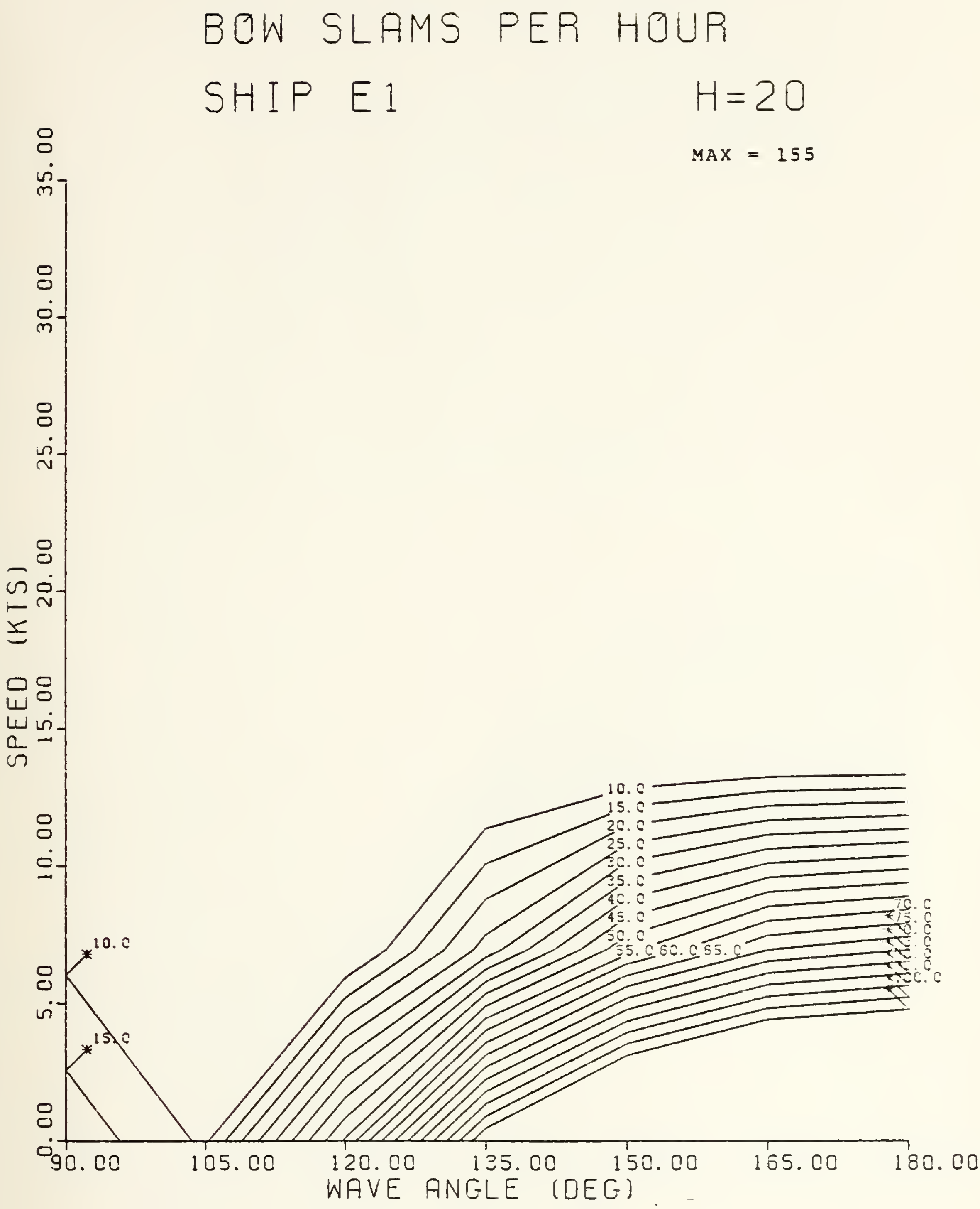
OPERATING ENVELOPE DUE TO A MAXIMUM PERMISSIBLE BOW ACCELERATION OF 6.4 FT/SEC^2


BOW SLAMS PER HOUR
SHIP E1
H=5
MAX = 0.0
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)

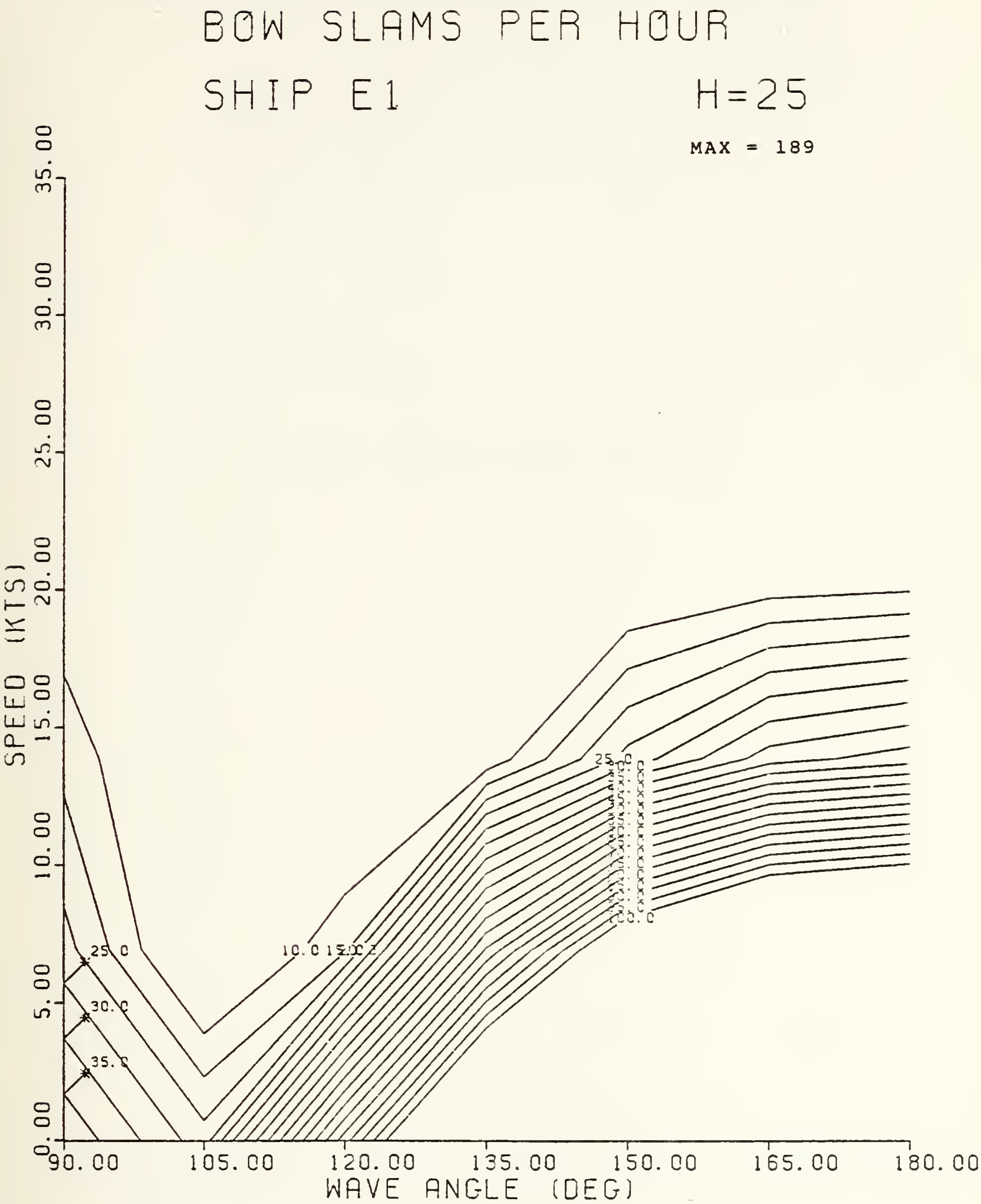
BOW SLAMS PER HOUR
SHIP E1
H=10
MAX = 0.0499
SPEED (KTS)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



BØW SLAMS PER HOUR
SHIP E1
H=15
MAX = 76.7
SPEED (KTS)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
WAVE ANGLE (DEG)



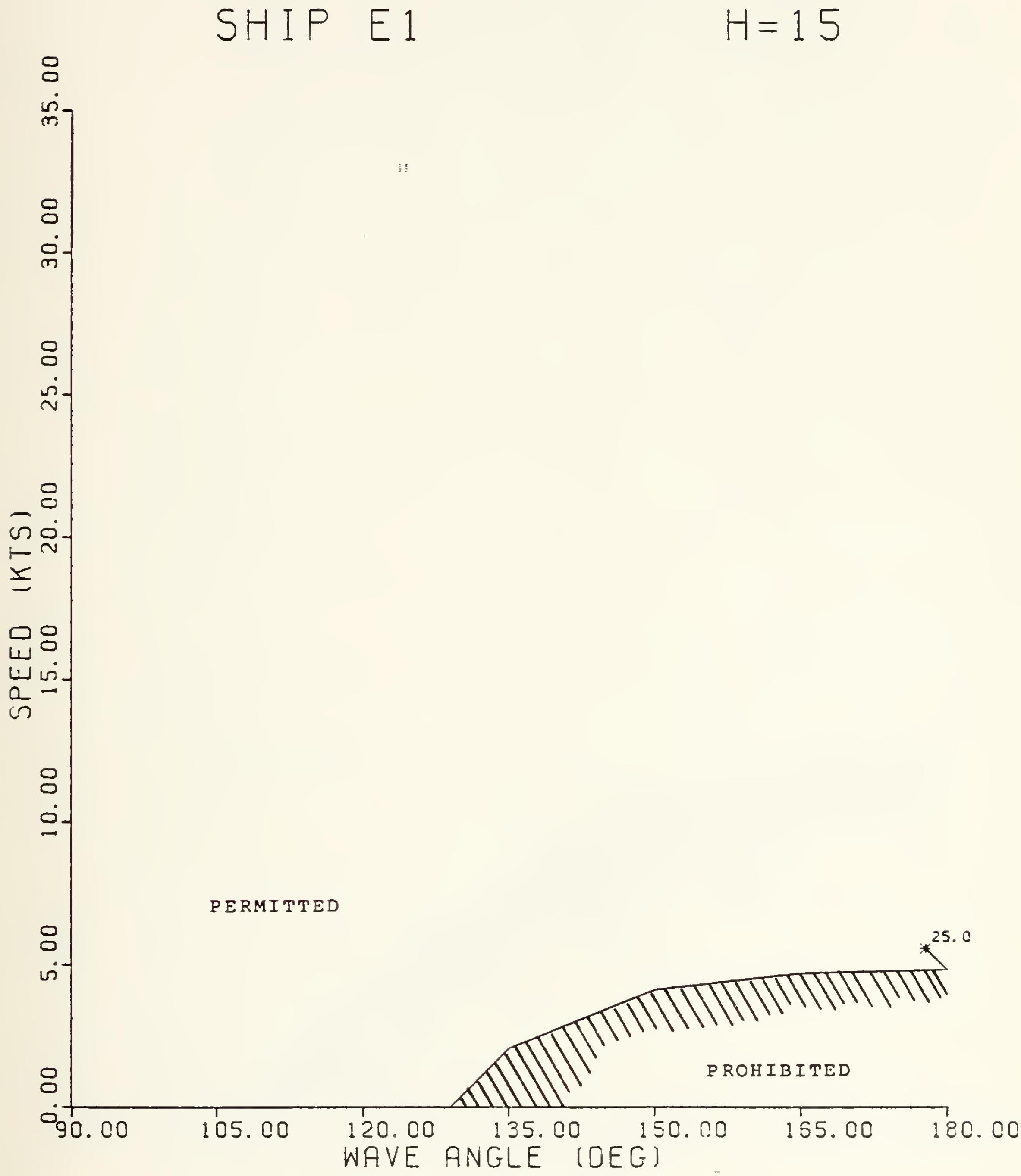
BOW SLAMS PER HOUR
SHIP E1
H=20
MAX = 155
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0


BOW SLAMS PER HOUR
SHIP E1
H=25
MAX = 189
SPEED (KTS)
WAVE ANGLE (DEG)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
90.00
105.00
120.00
135.00
150.00
165.00
180.00
25.0
30.0
35.0
10.0
20.0

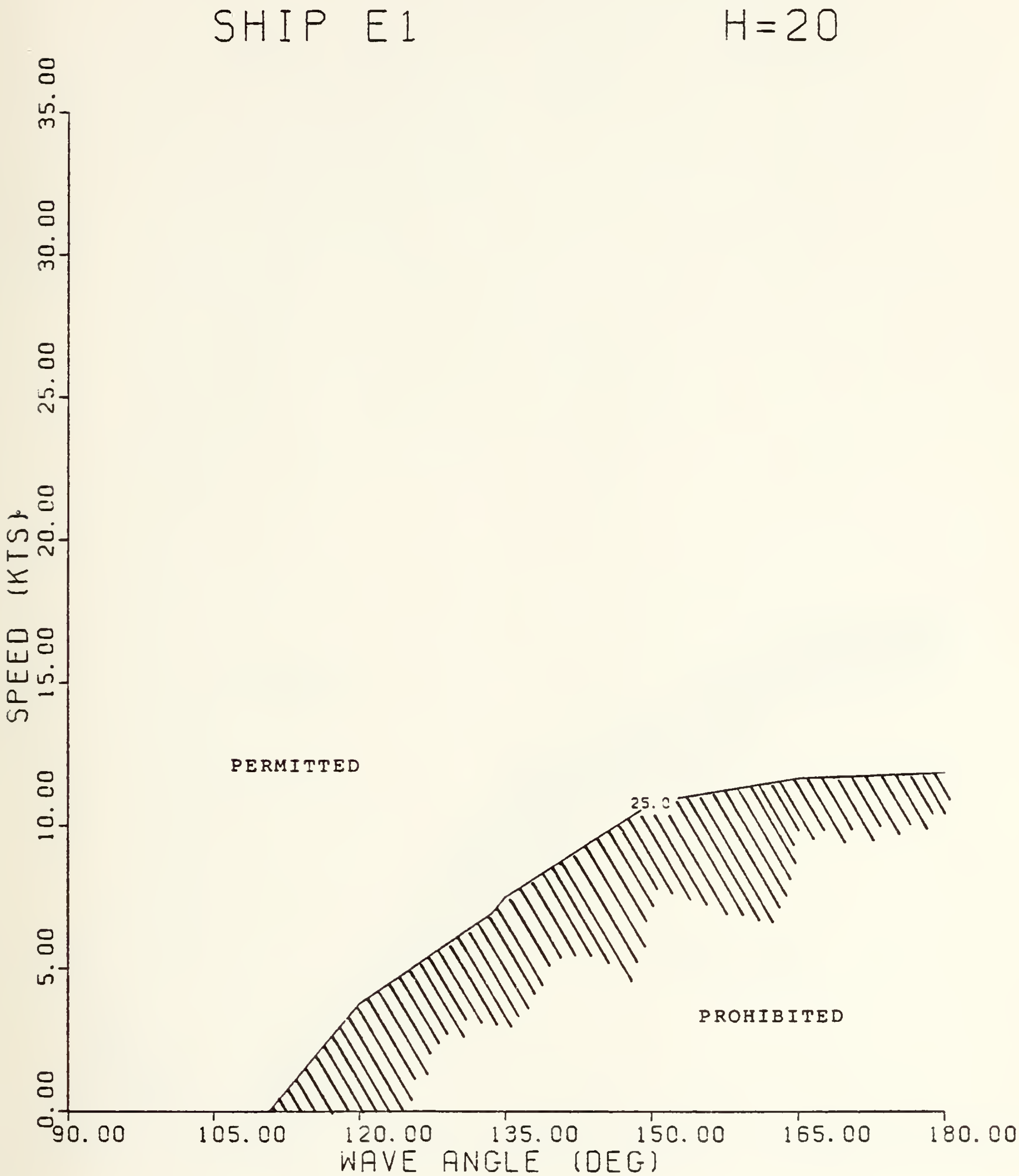
OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR



OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR



OPERATING ENVELOPE DUE TO A MAXIMUM
PERMISSIBLE BOW SLAMMING FREQUENCY OF 25/HR

APPENDIX C

Appendix C is a collection of plots which show the regions in which the ship may be operated without exceeding the specified criteria. Plots are not given for a significant wave height of five feet since none of the ships were limited by any of the criteria for that wave height. The shaded side of a curve denotes the prohibited operating region.

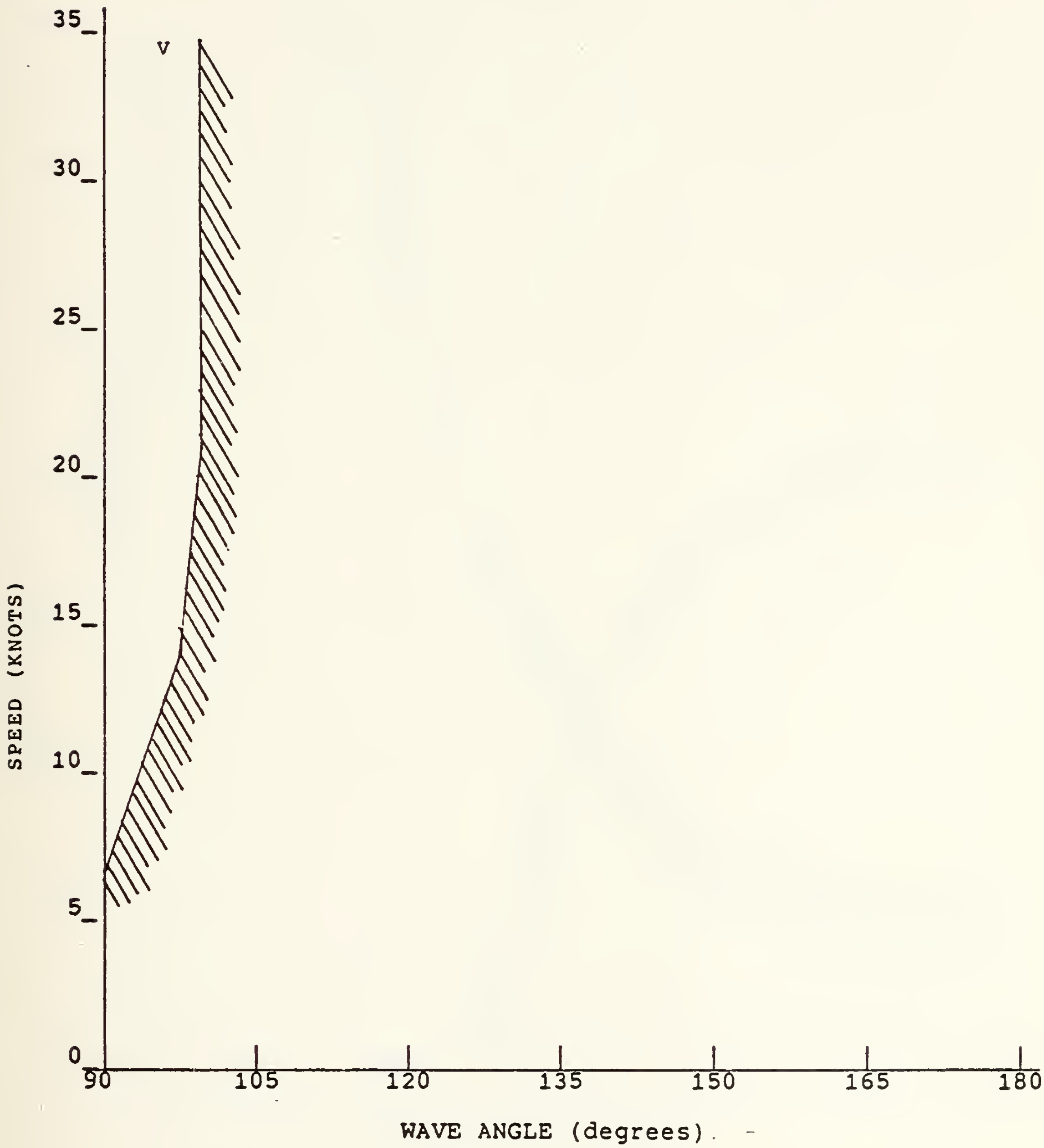
Criteria	Critical or Limiting Value
Bow motion	2.1 feet
Bow velocity	3.5 ft/sec
Bow acceleration	6.4 ft/sec^2
Bow slams	25/hr

ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING THE INDICATED LIMITING CRITERIA

SHIP B0 H = 10

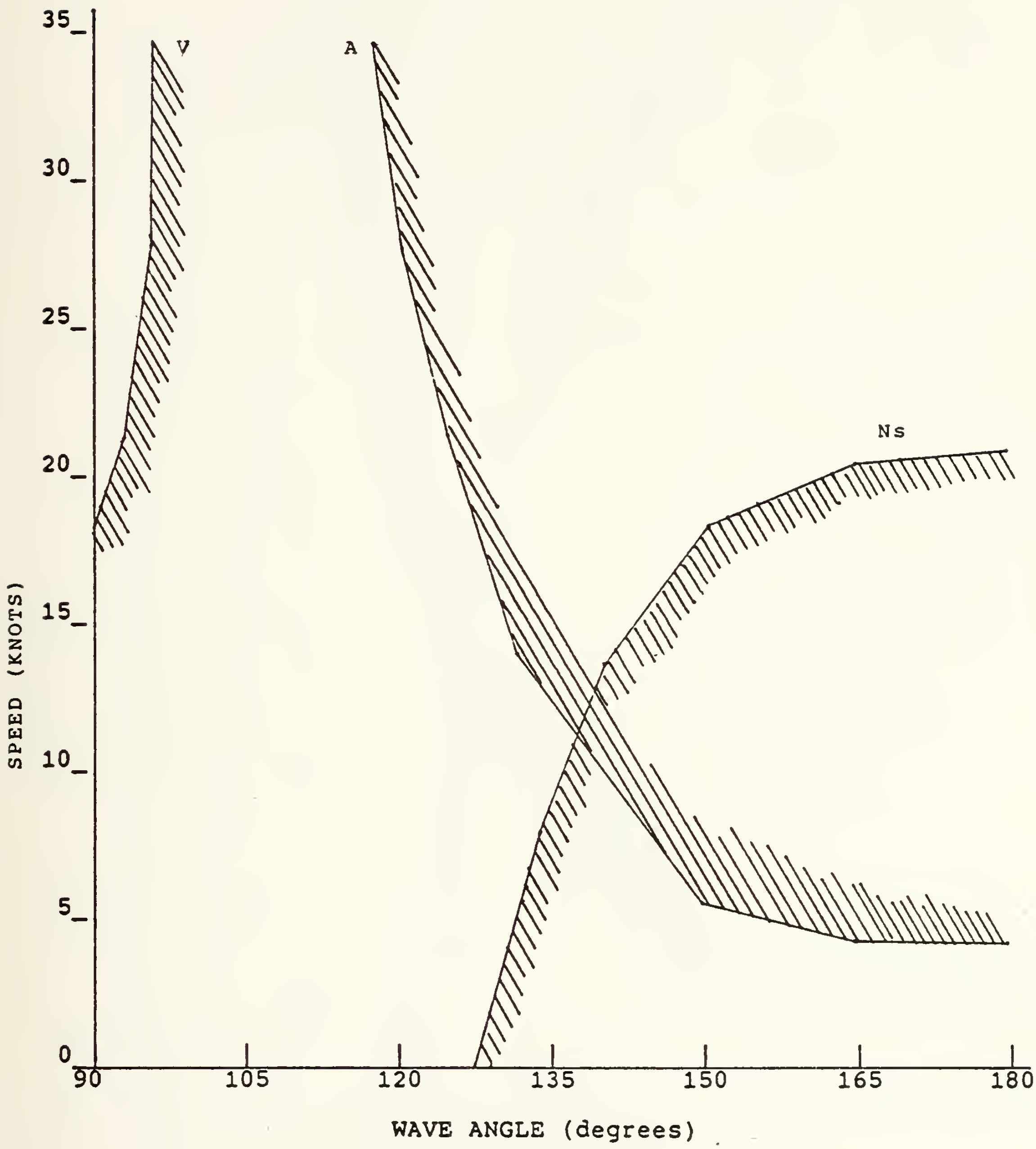
ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B0 H = 15



ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B0 H = 20



ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

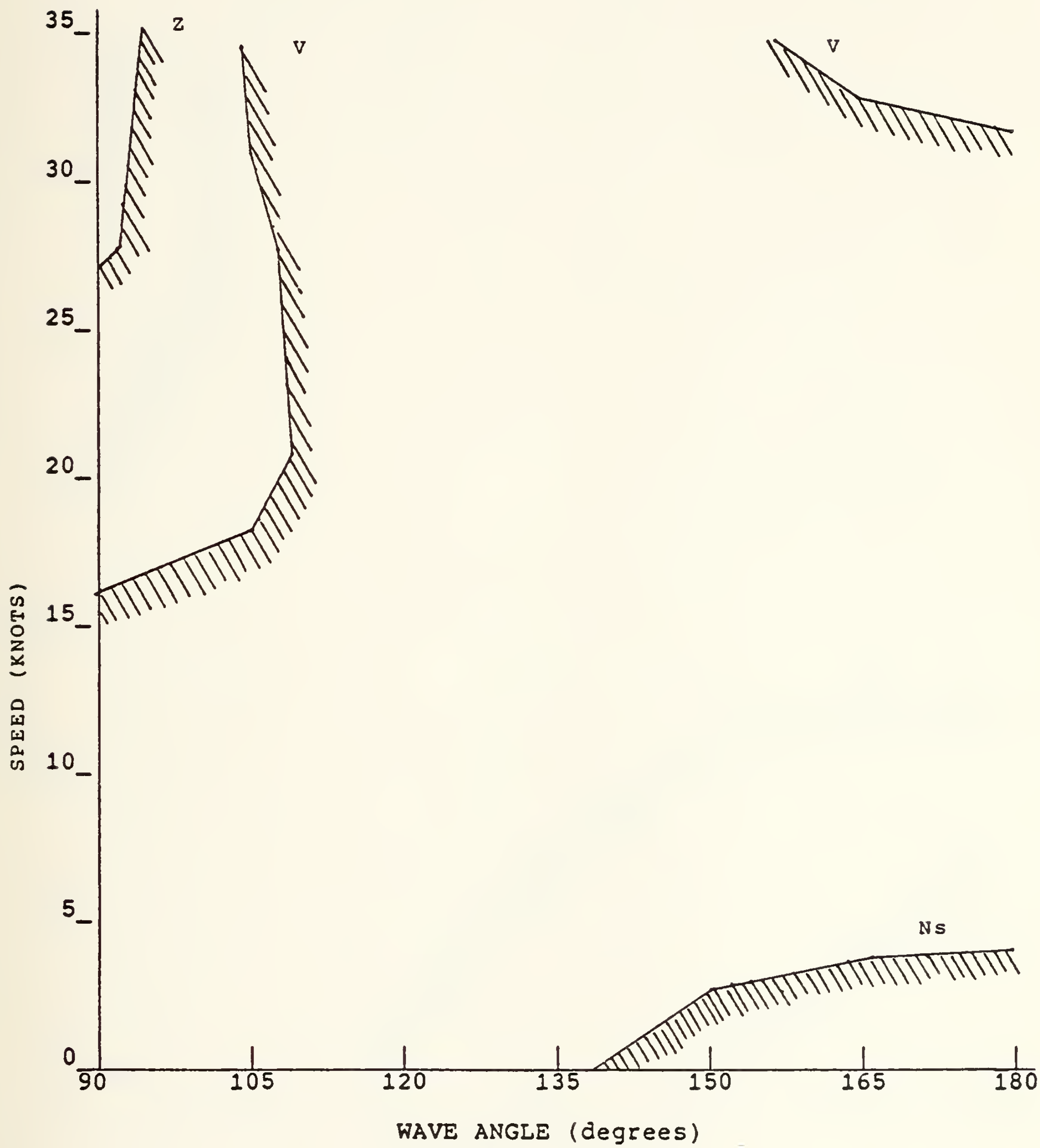
SHIP B0 H = 25

ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B1 H = 10

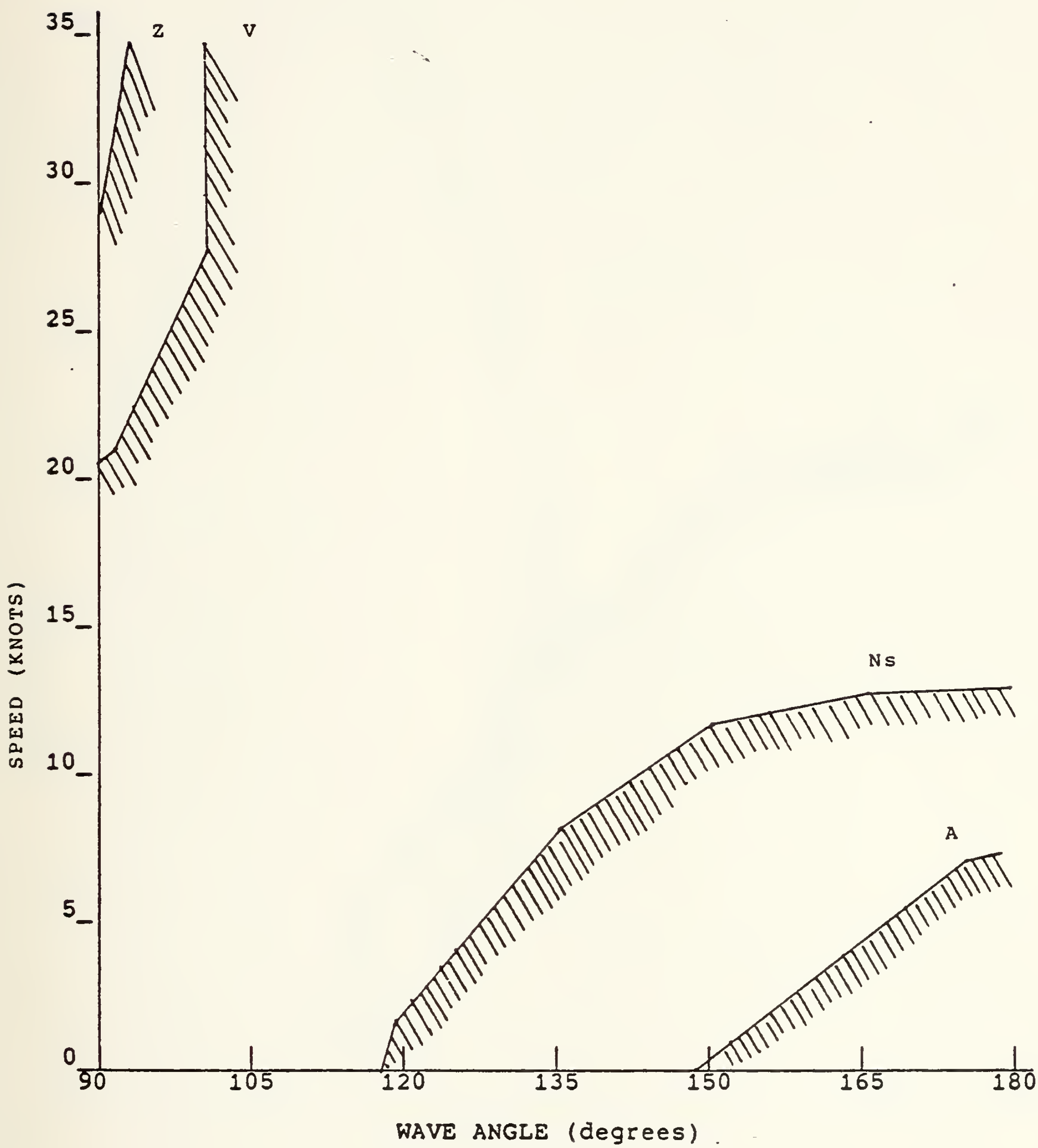
ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B1 H = 15



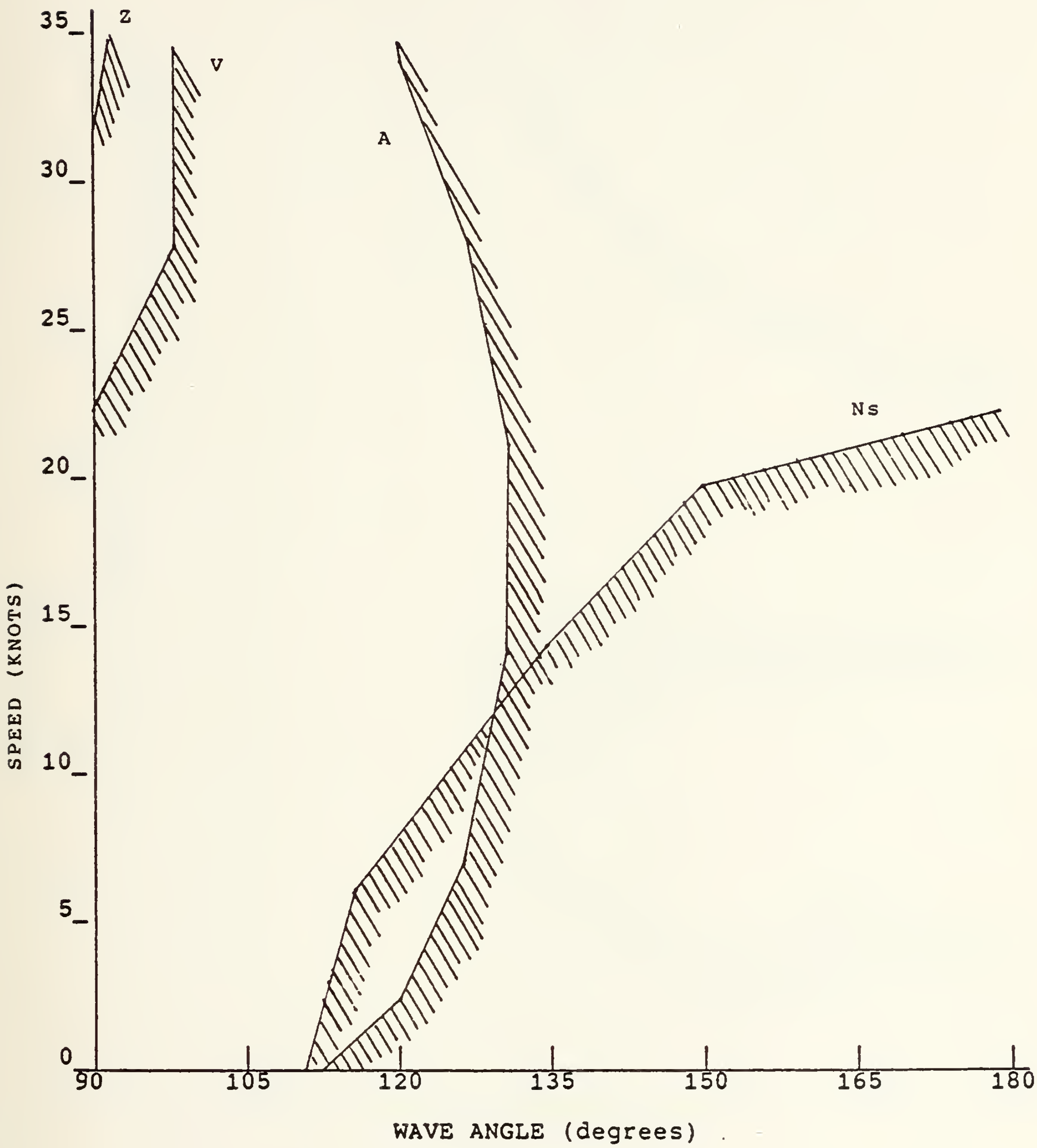
ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B1 H = 20



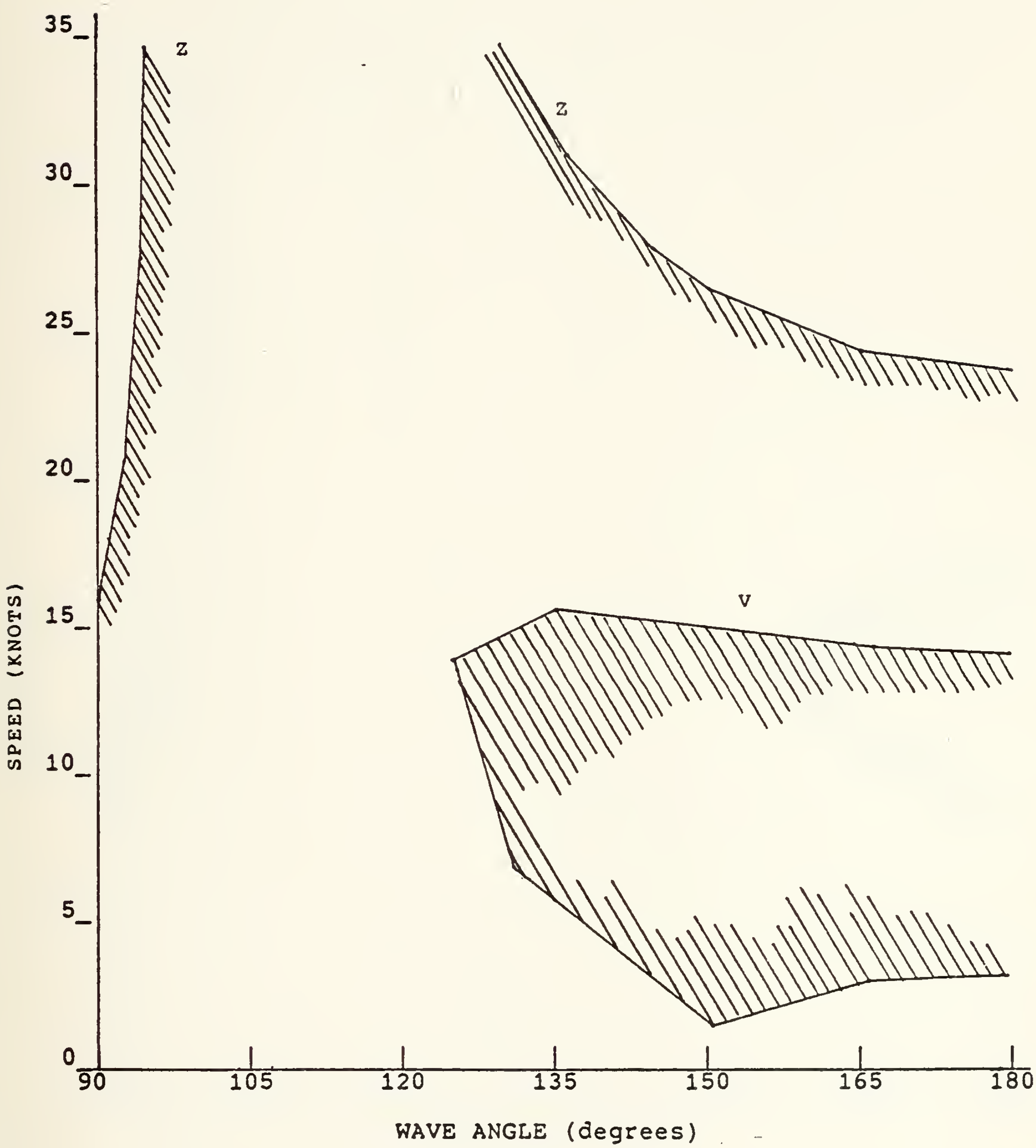
ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP B1 H = 25



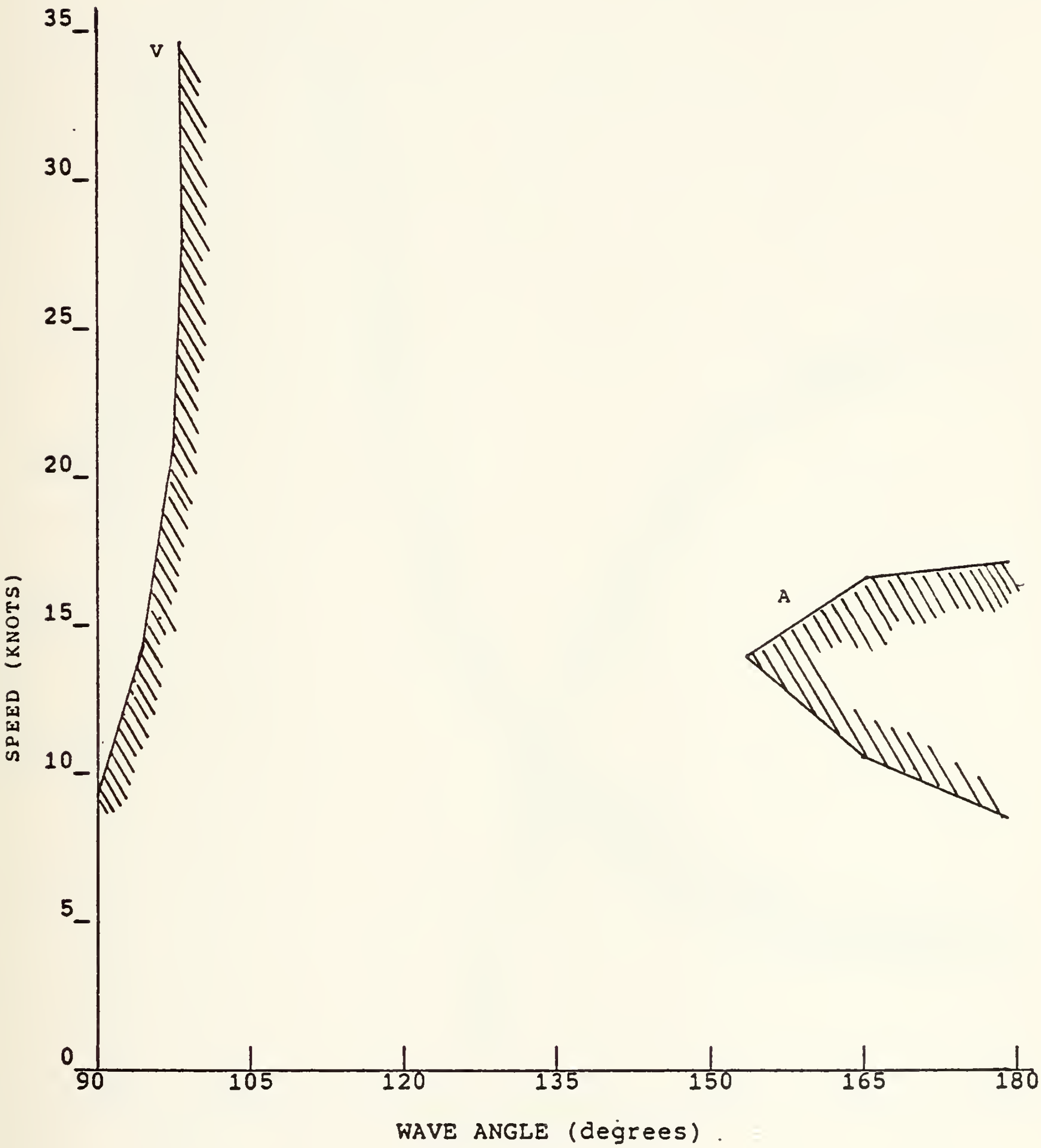
ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E0 H = 10



ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E0 H = 15

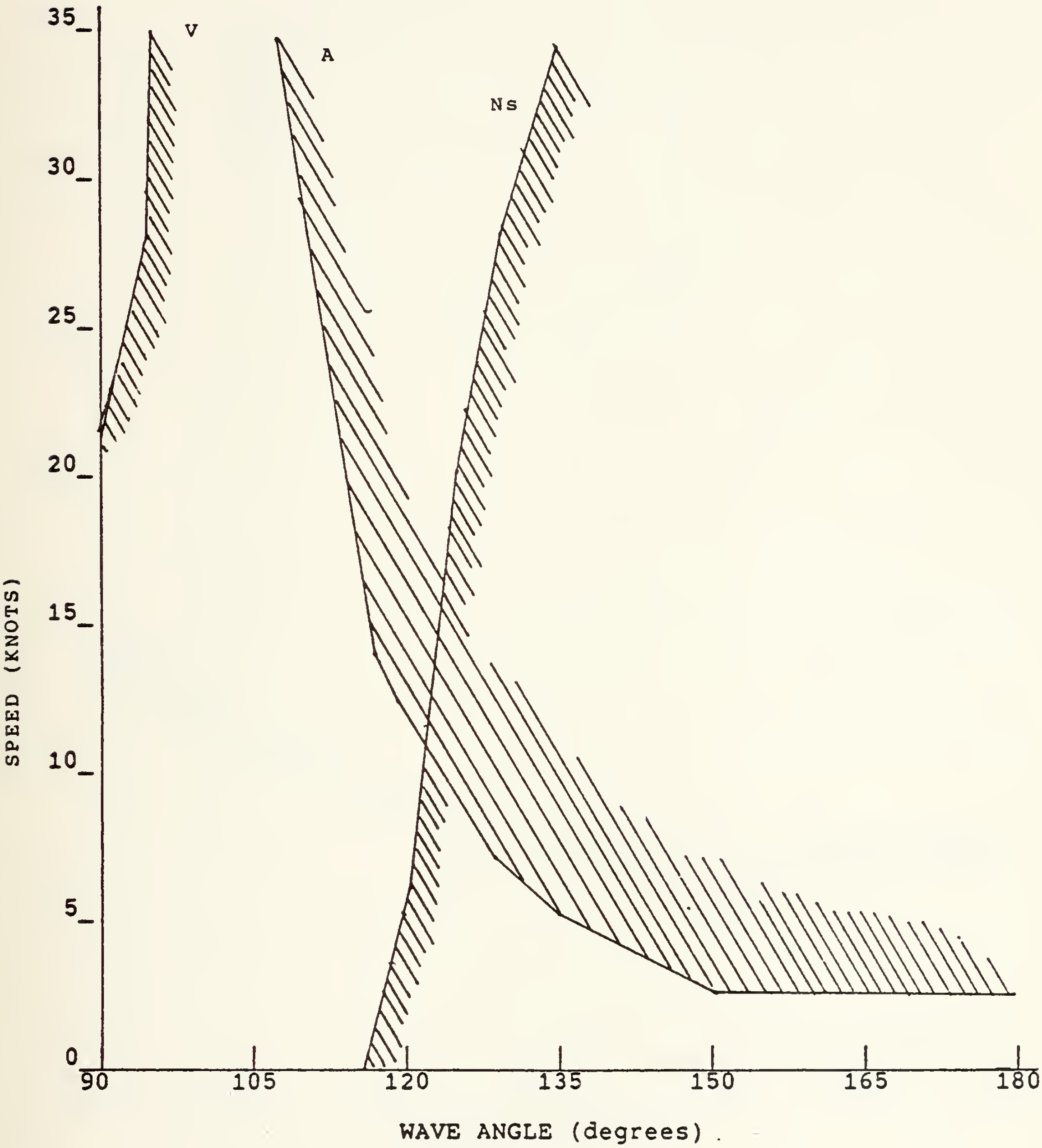


ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E0 H = 20

ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E0 H = 25

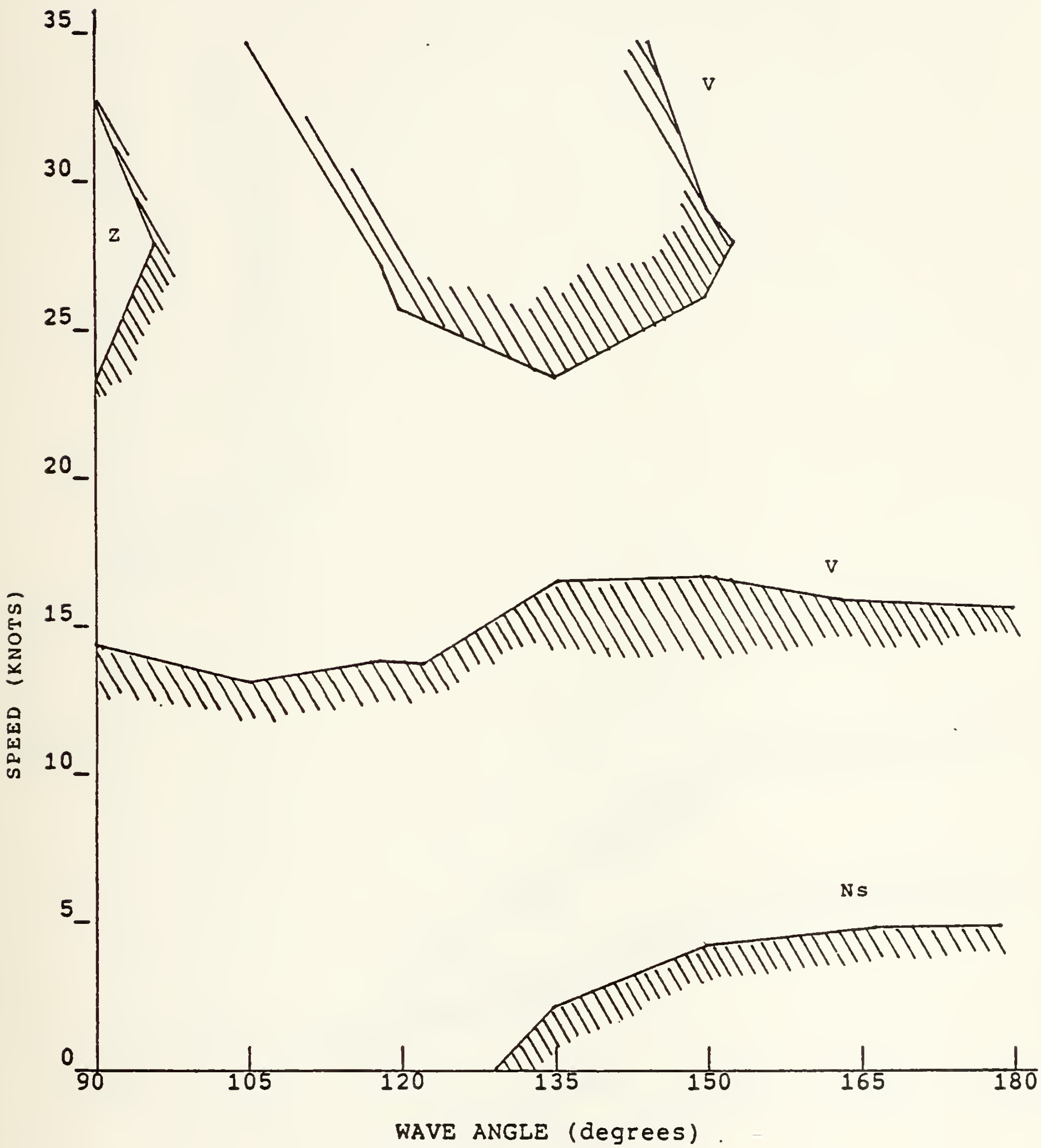


ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E1 H = 10

ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E1 H = 15



ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E1 H = 20

ALLOWABLE SPEED AND WAVE ANGLE WITHOUT EXCEEDING
THE INDICATED LIMITING CRITERIA

SHIP E1 H = 25